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A regional computable general equilibrium model for fisheries: results of the EU PECHDEV project

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Abstract

This paper presents 1-an application of the Computable General Equilibrium (CGE, hereafter) technique to fisheries using data from five EU regions: Bornholm (Denmark), Salerno (Italy), Cornwall (England), Finistère (France) and Pontevedra (Spain); 2-the biological production functions for these NUTS 3[1] EU regions (County in England, Département in France, Province in Italy and Spain, Municipality in Denmark) and ; and 3-some key ecological aspects to take into account when modelling fisheries. The data requirements for regional CGE and biological models are explained, and the process to be used to develop applied static CGE models for the fisheries sector is also presented. The main purpose of this paper is to present the use of a CGE model for policy and decision-making purposes by looking at the empirical relationship between fisheries and regional economics. For this, two policy scenarios are considered: (i) an increase in taxes, and (ii) a decrease in production quota. The Pechdev model offers some interesting conclusions that help us 1-to better understand fisheries economic modelling when considered as a separate sector in interaction with the rest of the economy; 2-to give inputs to the European Common Fishery Policy. The results of scenarios are limited to the economy as the link between economic and biological models has not been successfully set up for various reasons, particularly the data problems with the selected regions.
Keywords: CGEM, fishery; Region; Development

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[1] NUTS: nomenclature of territorial units for statistics used by Eurostat. NUTS 3 refers to administrative units comprising between 150 000 and 800 000 inhabitants.

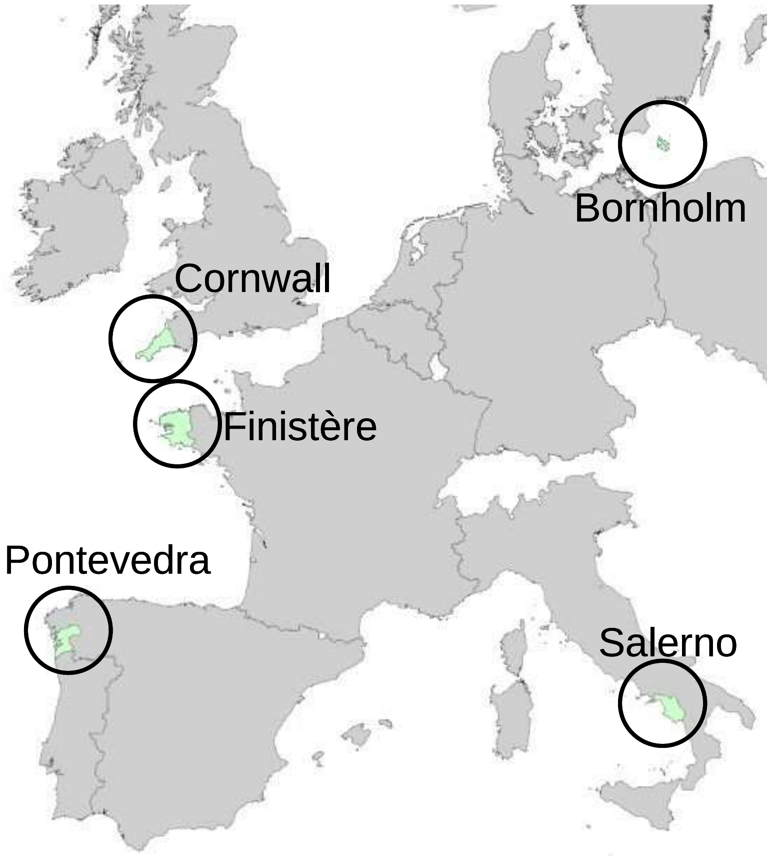

Figure 1: Case studies location

1 Introduction

In recent decades many Computable General Equilibrium (CGE) models have been developed to address economy-wide issues. Based on rigorous microeconomic theory and complemented with the Social Accounting Matrix (SAM), the CGE model has become one of the best tools to mimic the economy and is powerful for policy analysis.

This paper presents a dynamic fishery CGE model to be applied for five regions of five European countries, one for each country. We first will briefly review some basics of the CGE modelling and then discuss the construction of the model with particular extension to fisheries. The main goal of this project is to develop a CGE model for the evaluation of the socio-economic contributions of the fishing activities. From fishery management and regional development point of view, it is interesting to employ a regional economic model and estimate the regional economic impacts attributable to fishery policies. To the best of our knowledge, this regional model is the first CGE model applied to fisheries, except for the unpublished work by Houston et al (1997). The model is computed using GAMS software package[2].

Information dealing with population dynamics is very heterogeneous among fish species and stocks in Europe. Data can be accurate for fish stocks of high commercial interest or submitted to an intense fishing pressure, hence generally displaying characteristics of overexploitation (e.g. North sea cod). On the contrary, information is very scarce and scattered for the majority of species not submitted to quota management and generally of

2 GAMS (*G*eneral *A*lgebraic *M*odelling *S*ystem) is an optimisation software, popularly used among applied economists (see www.gams.com).

lower commercial interest. However, the sum of all these species can represent an important part of landings in many regions. The absence of clear knowledge on the state of these stocks can impair a good management in some fisheries because the intensity of fishing effort can largely exceed their potential of biological production.

Some key stocks or species for each region were selected in order to well understand the coupling between the dynamics of their corresponding populations and the regional economics. The choice of the stocks mainly relied on their economic importance notwithstanding the amount of biological knowledge available. Further, appropriate production functions had to be defined for all stocks selected in order to estimate economic results of fisheries sector and to establish a link between biology and economy.

For homogeneity and simplicity, the choice was made to use surplus production models (also called biomass dynamics models) in the form of exponential (Fox, 1970) or generalized (Pella and Tomlinson, 1969) production models. First, this choice was made to avoid the use of the Schaefer models (Schaefer, 1954) that is generally employed in bioeconomic approaches and considered over-pessimistic (Maunder, 2003). The Schaefer model has also been criticized for giving surplus production curves being perfectly symmetric to stock size and having its maximum at a stock size of exactly one-half of the theoretical maximum size (Pella and Tomlinson, 1969; Hilborn and Walters, 1992; Maunder, 2003). In practice, many authors have remarked that for many fish populations, the curve may well be skewed, with the maximum occurring at stock sizes less than half the maximum stock size (Hilborn and Walters). Pella and Tomlinson (1969) proposed the addition of a supplementary shape parameter to allow the production relationship to be skewed to the left or to the right. The methods performed in the section 4.2 then focus on the exponential and generalized production models rather than on the logistic model of Schaefer (1954).

Moreover, surplus production models allow to easily express the population biomass in function of the yield made on the stock through a discrete equation (see below), something difficult with age-structured models. For species without good information on population dynamics, it is possible to establish empirical functions from catch time-series and based on strong assumptions (Gulland, 1971; Garcia *et al.*, 1989). Finally, these models are pretty easy to be manipulated because they only require a few parameters that can be expressed in function of ecological metrics (e.g. pollution) or variables (e.g. predator biomass in the ecosystem) in order to add an ecological dimension to the approach.

In this context and according to the data available for the stocks or species of interest in the PECHDEV project, two different routes were used to estimate the biological productions required in the computable general equilibrium model (CGEM). First, the species taken into account were those that supported the main fisheries and for which production model parameters could be estimated. Second, the species and trophic links between them included in the GM were constrained by the assumptions and constraints of the economic part of the model.

The economic model, based on the economic theory, was developed using data from Social Accounting Matrix (SAM). It was conceived to be an annual model. All economic data refer to a given year (2001). The biological model, through the current yield, is necessarily subordinated to those restrictions. It cannot take into account seasonal variations as the yield is annual. Therefore, biological production functions were conceived as surplus production models using annual time series.

The ecological box is considered in the model as a set of ecological factors able to influence the stock dynamics through the biological parameters considered for the production functions selected.

On the other hand, the ecological description and ecological parameters taken into account are concerned within the coastal area of the Salerno province, but this could be easily generalised for other areas.

The paper is organised as follows: Section 2 presents an overview of a static CGE model applied in fisheries and describes the data requirement. The biological model and the ecological parameters are also presented. In Section 3 main empirical results are reported for the five European regions selected. Section 4 discusses the main findings. Finally, Section 5 concludes the paper and proposes future research.

2 Methodology

2.1 A Computable General Equilibrium Model for Fisheries

2.1.1 Overview of the model

The general equilibrium approach on the economy is based on neoclassical economic theory. According to the Arrow-Debreu theorem, assuming that the economy consists of a number of markets each of which is responsible for a commodity and that the economy is operated by a set of agents who are either producers or consumers of the commodities, individually price-takers, and aim to optimize their own profits, costs or utility, under general conditions, there exists a set of prices simultaneously clearing all commodity and factor markets and fulfilling agents' individual objectives. The economy then is in equilibrium. Economic policy analysis is often conducted to assess the responsive effects of agents and markets when the price system is interrupted by policy instruments.

Advancing from the traditional planning models, Dervis, de Melo and Robinson (1982) developed a static computable general equilibrium model to assist policy analysis for the decentralised economy. Many features of the model such as market mechanism, policy instrument, price adjustment, industrial structure, institutions, and foreign trade now have become popular among detailed CGE modelling works. Lofgren *et al* (2001) recently extended the model to allow for the ability of producers to produce more than a single commodity. In the PECHDEV project, we develop a fisheries CGE model on basis of rigorous economic theory and standard methods and with particular consideration on fisheries. The model assumes perfect competition among producers, constant returns to scale production, and rational economic agents who optimize their behavior. It allows each producer to produce multiple products and each product to be produced by multiple producers. The production technology is multi-level nested. At the top level, the Leontief technology is adopted to specify the fixed relationship between aggregate intermediate and value-added inputs. At the bottom level, the Leontief technology is also adopted to specify the fixed proportions of disaggregate intermediate inputs, while the CES technology is used to allow substitution between the primary inputs of labor and capital. In commodity markets, aggregate domestic production is allocated between domestic sales and aggregate exports. With the Armington assumption domestic sales and aggregate imports together form aggregate domestic supply, which is used for domestic intermediate use, household consumption, government consumption, and investment.

The factor incomes are calculated from factor employment and prices, and then distributed among institutions in the fixed shares that are calibrated from real data. The income transfers among institutions are also calculated in the fixed shares that are calibrated from real data. The final income of an institution is the sum of the institution's net factor and transfer incomes, and linked to expenditures, which include consumption and savings. Household marginal propensity to save is exogenous in the model. After deducting household savings from household disposable income, household consumption demand is obtained. Each household is assumed to maximize a "Stone-Geary" utility function subject to a consumption expenditure constraint. The resulting first-order condition is a linear expenditure function of total consumption spending. Fixed invest demand is defined as the base-year quantity multiplied by an exogenous adjustment factor. Similarly, government consumption demand is defined as the base-year quantity multiplied by an exogenous adjustment factor.

The main constraints of the model require clearings in all commodity and factor markets. In the commodity markets, both supply and demand of commodities are subject to relative price change. However, in the factor markets, as factor supplies are simply fixed, factor demands are thus adjusted merely through factor prices.

This project is intended to apply general equilibrium approach of fisheries economics to five NUTs3 regions. Because of the heterogeneity of these regional economies, uniformed classifications of agents and products across the regions cannot be applied. Instead, the model has to be set up with different versions, one for each region. In this sense regional dimension need not be specified within the model. However, the model has multiple sectors. At the top level there are fisheries and non-fisheries sectors. The non-fisheries sectors are aggregated into agriculture, energy, industry and services sectors. The fisheries sector consists of wild capture, aquaculture, processing, marketing and fisheries-related business services sub-sectors. Within the fisheries sector a number of producers are distinguished by fleet type with regional variations. Similarly, at the top level of commodity there are fish and non-fish products, and the fish products are divided into species with regional variations. The model considers government and two types of households, namely depending or not depending on fisheries activity. The model has dynamic property and includes bioeconomic growth functions, thus permitting analysis on interactions between economic and marine ecological systems.

2.1.2 The classifications of agents and markets in the basic model

The model currently developed is the basic model, the classifications of which cannot be uniformly applied to any regional economy. They need further changes subject to each region's special economic conditions. However, the basic model provides a general structure for modification.

For the consumers, we have

- 0. Households of fisheries, which are further distinguished into
    - 1. Households depending on managers of fishery industries
    - 2. Households depending on skilled fishers
    - 3. Households depending on unskilled workers of fishery industries
- 4. Households of agriculture excluding fisheries
- 5. Households of non-fishery and non-agriculture
- 6. Households depending on capital income
- 7. Government
- 8. Foreign consumers

This classification is set up with consideration that the consumers may have different consumption propensity to aquatic products mainly due to the difference in income level.

For the producers, let IM, VA, K and L denote imtermedaite uses, value-added, capital and labour, respectively, we have

- 0. Fisheries
    - 1. Large and medium-scale harvesters or metiers (nearly Leontief technology)
    - 2. Small-scale fisher (nearly Leontief technology)
    - 3. Aquaculture producers (nearly Leontief technology)
    - 4. Fish processing (Nested CES technology – IM and VA, - IMs, - K and L)
    - 5. Fish marketing (Nested CES technology – IM and VA, - IMs, - K and L)
    - 6. Fishery-related business service (Leontief technology)
- 7. Agriculture excluding fisheries (Nested CES technology – IM, L and K, - IMs)
- 8. Energy (Nested CES technology – IM, L and K, - IMs)
- 9. Industry excluding energy (Nested CES technology – IM, L and K, - IMs)
- 10. Service excluding fish marketing and business services (Nested CES technology – IM, L and K, - IMs)

Since the focus of the model is on fisheries, for simplicity we aggregate all non-fishery related industrial sectors into a single industrial sector, all non-fishery related service sectors into a single service sector. We separately take the agriculture and energy sector, considering their special relations with fisheries. Modern fishing activity relies heavily on fuels, the price change of which will have implications on fishing activity. The abatement of climate change therefore is relevant to fisheries. Agriculture has the closest link with fisheries, not only the sectors' products are highly substitutable but also production factors are highly mobile between the sectors.

For the production factors, we have

0. Labour
    1. Managers of fishery industries
    2. Skilled fishers
    3. Unskilled workers of fishery industries
    4. Farmers
    5. Other sectors' employment
6. Capital

There could be different treatments regarding the mobility of both capital and labour. For simplicity, in the basic model we assume both rental and wage rates are exogenous and thus capital and labour supplies are inelastic in response to factor prices. In other scenarios we could allow for labour mobility between farmers and unskilled fishers.

For the commodities, we have

0. Fishes by type - basic and luxury brand of fishes, and raw and processed aquatic products. Each type consists of a number of individual species:
    1. Species 1
    2. Species 2
    … … …
    s. Species s
    s+1. Fisheries services
s+2. Agricultural product
s+3. Energy product
s+4. Industrial product
s+5. Services other than fisheries service

It is assumed that each of the agriculture, energy, industry and service sectors only produces a single product and each metier may produce multiple species of fishes.

2.1.3 The structure of the model

2.1.3.1 Consumers' behaviour

The consumption follows a nested system (Appendix 1*A*) in which consumers wish to maximize utility across time periods by optimally allocating aggregate consumption over time periods (the Ramsey rule). The model distinguishes six types of households, each of which is assumed to consist of identical consumers. Household consumption is defined according to a multi-level nested system. At the top level, the behaviour of each type of households can be modelled through one representative consumer who maximizes her intertemporal utility subject to an intertemporal budget constraint for a particular duration of time. The representative consumer's objective is

$$W = \max \sum_{t=1}^{T} (1+\rho)^{t-1} u(c_t) = \max \sum_{t=1}^{T} (1+\rho)^{t-1} \ln(c_t)$$

where ρ is social or pure time preference or discount rate and c_t is aggregate consumption in volume at time t. The utility function is the logarithm of aggregate consumption. The time duration has T periods.

Subject to

$$E_1 \equiv \sum_{t=1}^{T} (1+\gamma)^{T-t} p_t c_t + s_T = \sum_{t=1}^{T} (1+\gamma)^{T-t} y_t + (1+\gamma)^T s_0$$

where E_1 is life-time expenditure, γ is real interest rate, p_t and y_t are consumption price and income at time t, and s_0 and s_T are exogenous initial and end period savings, respectively. The left-hand side of the above equation is the consumer's lifetime spending and the right-hand side the lifetime income.

The Lagrangian for the above intertemporal optimization problem can be written as

$$L = \sum_{t=1}^{T} (1+\rho)^{t-1} u(c_t) + \lambda \left[\sum_{t=1}^{T} (1+\gamma)^{T-t} y_t + (1+\gamma)^T s_0 - \sum_{t=1}^{T} (1+\gamma)^{T-t} p_t c_t - s_T \right]$$

The $T+1$ FOCs (first order conditions for λ and variables $c_1\, c_2 \ldots c_T$) are

$$\sum_{t=1}^{T} (1+\gamma)^{T-t} p_t c_t + s_T = \sum_{t=1}^{T} (1+\gamma)^{T-t} y_t + (1+\gamma)^T s_0 \qquad \text{(1 equation)}$$

$$(1+\rho)^{t-1} u'(c_t) - \lambda (1+\gamma)^{T-t} = 0 \qquad (T \text{ equations})$$

Eliminating λ by comparing up T FOCs excluding the budget constraint, we obtain the following solution system for consumption variables $c_1\, c_2 \ldots c_T$

$$\sum_{t=1}^{T} (1+\gamma)^{T-t} p_t c_t + s_T = \sum_{t=1}^{T} (1+\gamma)^{T-t} y_t + (1+\gamma)^T s_0 \qquad \text{(1 equation)}$$

$$u'(c_t) = (1+\rho)(1+\gamma) u'(c_{t+1}) \text{ or } c_t = (1+\rho)(1+\gamma) c_{t+1} \qquad (T-1 \text{ equations})$$

Obviously, the consumption demand depends on both consumption price and income level, which are determined in price system and factor income distribution.

Having defined aggregate consumption in each period, next step moves to the second level of the consumption system to disaggregate the aggregate consumption in each period into four consumption or commodity categories, namely agro&aqua-product, energy, industrial product, and service. The demands for these products are derived from minimization of consumption expenditure at a given level of utility in a period. Assuming that each of the consumption or commodity categories also includes a minimum obliged consumption as a part, and that budget share of expenditure on each of the category is fixed and all shares sum up to 1, we adopt the Stone-Geary utility function and then have the following total expenditure function in period t

$$E_2 \equiv p_t c_t = \sum_{i=1}^{4} p_{t,i} \underline{c}_{t,i} + u(c_t) \prod_{i=1}^{4} p_{t,i}^{\beta_i}$$

where E_2 is total expenditure for the second level of consumption at period t, $p_{t,i}$ is commodity *i*'s price, $\underline{c}_{t,i}$ the minimum obliged or subsistence consumption of commodity i, and β_i the marginal budget share of consumption of commodity i. Minimizing the above expenditure function, we obtain the Hicksian derived demand function with respect to each commodity

$$c_{t,i} = \underline{c}_{t,i} + \left(\frac{\beta_i}{p_{t,i}} \right) \left(p_t c_t - \sum_{i=1}^{4} p_{t,i} \underline{c}_{t,i} \right) \qquad \text{(4 equations)}$$

The above equation says that the Hicksian derived demand for a commodity depends on relative prices, aggregate consumption, and shares. The minimum obliged consumption $\underline{c}_{t,i}$ can be either exogenously given or endogenously determined according to defined relationships with relative prices, aggregate consumption, budget shares, and expenditure elasticity[i].

Among the four commodities at the second level of consumption, energy, industrial product and service are final products produced by respective sectors, while agro&aqua-product is a hypothetical, composite product, which need be disaggregated further into agricultural and aquatic products at third level of consumption. Such design allows greater substitutability between the two products. Here, we assume the CES utility function and have the following expenditure function

$$E_3 \equiv p_{t,aa}c_{t,aa} = u(c_{t,aa})\left(\beta_{ag}\, p_{t,ag}^{1-\sigma_3} + \beta_{aq}\, p_{t,aq}^{1-\sigma_3}\right)^{\frac{1}{1-\sigma_3}}$$

where E_3 is total expenditure for agricultural and aquatic products, $p_{t,aa}$ and $c_{t,aa}$ are price and consumption of the composite agro&aqua-product, respectively. σ_3 is substitution elasticity at the third level of consumption, and β_{ag} and β_{aq} are share parameter of agricultural and aquatic price, respectively. Minimizing the above expenditure function, we obtain the Hicksian derived demand function with respect to each of agricultural and aquatic products

$$c_{t,i} = \frac{\beta_i p_{t,i}^{-\sigma_3}}{\sum_i \beta_i p_{t,i}^{1-\sigma_3}}\, p_{t,aa}c_{t,aa}, \quad i \in (ag, aq) \qquad \text{(2 equations)}$$

where agricultural product, $c_{t,ag}$, is final product of agricultural sector but aquatic product, $c_{t,aq}$, is a composite product of aquatic sector, which need be disaggregated further into two types, namely luxury and basic aqua-products, to allow for lower substitutability between them. This moves us to fourth level of consumption. We again assume the CES utility function and have the following expenditure function

$$E_4 \equiv p_{t,aq}c_{t,aq} = u(c_{t,aq})\left(\beta_{lu}\, p_{t,lu}^{1-\sigma_4} + \beta_{ba}\, p_{t,ba}^{1-\sigma_4}\right)^{\frac{1}{1-\sigma_4}}$$

where E_4 is total expenditure for luxury and basic aquatic products, σ_4 is substitution elasticity at the fourth level of consumption, and β_{lu} and β_{ba} are share parameter of luxury and basic aquatic price, respectively. Minimizing the above expenditure function, we obtain the Hicksian derived demand function with respect to each of luxury (lu) and basic (ba) aquatic products

$$c_{t,i} = \frac{\beta_i p_{t,i}^{-\sigma_4}}{\sum_i \beta_i p_{t,i}^{1-\sigma_4}}\, p_{t,aq}c_{t,aq}, \quad i \in (lu, ba) \qquad \text{(2 equations)}$$

where each of luxury and basic aquatic products is distinguished between raw fish and processed product to consider substitution between them. This is done through the CES utility function and the following expenditure function

$$E_{5,j} \equiv p_{t,j}c_{t,j} = u(c_{t,j})\left(\beta_{ra,j}\, p_{t,ra,j}^{1-\sigma_{5,j}} + \beta_{pr,j}\, p_{t,pr,j}^{1-\sigma_{5,j}}\right)^{\frac{1}{1-\sigma_{5,j}}}, \quad j \in (lu, ba)$$

where $E_{5,j}$ is total expenditure for luxury or basic aquatic product, $\sigma_{5,j}$ is substitution elasticity at the fifth level of consumption, and $\beta_{ra,j}$ and $\beta_{pr,j}$ are share parameter of price of raw fish and processed aqua-product under luxury or basic category, respectively. Minimizing the above expenditure function, we obtain the Hicksian derived demand function with respect to each of raw (ra) fish and processed (pr) aqua-product under luxury or basic type

$$c_{t,i,j} = \frac{\beta_{i,j} p_{t,i,j}^{-\sigma_{5,j}}}{\sum_i \beta_{i,j} p_{t,i,j}^{1-\sigma_{5,j}}} p_{t,j} c_{t,j}, \quad i \in (ra, pr),\ j \in (lu, ba) \qquad \text{(4 equations)}$$

At bottom level of consumption each category of raw fish and processed aqua-product under luxury or basic type is distinguished among different species. We use the CES utility functions there to allow for high substitution among the species (sp). The expenditure functions are as follows

$$E_{6,j,i} \equiv p_{t,j,i} c_{t,j,i} = u(c_{t,j,i}) \left(\sum_s \beta_{s,j,i} p_{t,s,j,i}^{1-\sigma_{6,j,i}} \right)^{\frac{1}{1-\sigma_{6,j,i}}}, \quad s \in (1 \ldots sp_j),\ i \in (ra, pr),\ j \in (lu, ba)$$

where $E_{6,j,i}$ is total expenditure of each consumption category on the species, $\sigma_{6,j,i}$ is substitution elasticity at the sixth level of consumption, and $\beta_{s,j,i}$ is share parameter of price of each species of fish, respectively. Minimizing the above expenditure function, we obtain the Hicksian derived demand function with respect to each species of fish

$$c_{t,s,i,j} = \frac{\beta_{s,i,j} p_{t,s,i,j}^{-\sigma_{6,i,j}}}{\sum_s \beta_{s,i,j} p_{t,s,i,j}^{1-\sigma_{6,i,j}}} p_{t,i,j} c_{t,i,j}, \quad s \in (1 \ldots sp_j),\ i \in (ra, pr),\ j \in (lu, ba)$$

($2 \times (sp_{lu} + sp_{ba})$ equations)

These demands are final products of either fishing or processing sector. For simplicity we do not model marketed and home-consumed aqua-products here. Instead, we assume that all aqua-products are marketed. In future research, one can either assume fixed proportions of total aqua-products are marketed or follow the above way to model substitution between marketed and home-consumed aqua-products.

In summary, the consumption system consists of $T + 4 + 2 + 2 + 4 + 2 \times (sp_{lu} + sp_{ba})$ equations, $T + 8$ of which are composite products and the rest are real products produced by producers in the model.

2.1.3.2 Producers' behaviour

The production also follows a nested system (Appendix 1*B*) in which producers maximize net present value of revenue (profits) across time periods by optimally employing intermediate and factor inputs for production activity over time periods. The model distinguishes four general producers, namely agriculture, energy, industry and service, and a fishery producer, which is further classified into a number of fishery-related producers including several fishing producers, several aquaculture producers, a processing sector, a marketing sector, and a business service sector. The number of fishing or aquaculture producers varies subject to regional specification.

2.1.3.2.1 Agriculture, energy, industry or service producer

Each of the four general producers produces a single output and maximizes her intertemporal profit for a particular duration of time subject to intertemporal constraint of capital accumulation

$$V_j = \max \sum_{t=1}^{T} (1+r)^{-t} \left(p_{t,j} X_{t,j} - p_{t,io} X_{t,io} - w_t L_t - p_{t,I} I_t \right), \quad j \in (agr, eng, ind, sev)$$

where r is the real interest rate, X_t, $X_{t,io}$, L_t, and I_t are the general producer j's output, composite intermediate input bundle, labour and investment, respectively. $p_{t,j}$, $p_{t,io}$, w_t and $p_{t,I}$ are the corresponding prices. agr, eng, ind and sev represents agriculture, energy, industry and service, respectively. For convenience we omit the j subscript for all input terms.

Subject to

$K_{t+1} = (1-\delta)K_t + I_t$, and K_1, K_T given

where K_t is producer j's capital stock at time t, δ is the depreciation rate of capital, and K_1 and K_T are exogenous initial and end capital stock, respectively. Assuming aggregate production in each period takes the CES technology, we have

$$X_{t,j} = \left(\alpha_{io}^{\frac{1}{\rho}} X_{t,io}^{\frac{\rho-1}{\rho}} + \alpha_l^{\frac{1}{\rho}} L_t^{\frac{\rho-1}{\rho}} + \alpha_k^{\frac{1}{\rho}} K_t^{\frac{\rho-1}{\rho}} \right)^{\frac{\rho}{\rho-1}}, \quad j \in (agr, eng, ind, sev)$$

This dynamic optimization problem can be conveniently solved with the Bellman recursive method as below.

$$V_{t,j}(K_t) = \max \left[p_{t,j} X_{t,j} - p_{t,io} X_{t,io} - w_t L_t - p_{t,I} I_t + \left(\frac{1}{1+r} \right) V_{t+1,j}(K_{t+1}) \right]$$

The problem has the following FOC conditions

$$\frac{\partial V_{t,j}}{\partial X_{t,io}} \equiv p_{t,j} \frac{\partial X_{t,j}}{\partial X_{t,io}} - p_{t,io} = 0 \Rightarrow X_{t,io} = \alpha_{io} X_{t,j} \left(\frac{p_{t,j}}{p_{t,io}} \right)^{\rho} \qquad \text{(1 equation)}$$

$$\frac{\partial V_{t,j}}{\partial L_t} \equiv p_{t,j} \frac{\partial X_{t,j}}{\partial L_t} - w_t = 0 \Rightarrow L_t = \alpha_l X_{t,j} \left(\frac{p_{t,j}}{w_t} \right)^{\rho} \qquad \text{(1 equation)}$$

$$\frac{\partial V_{t,j}}{\partial I_t} \equiv -p_{t,I} + \left(\frac{1}{1+r} \right) \frac{\partial V_{t+1,j}}{\partial K_{t+1}} \frac{\partial K_{t+1}}{\partial I_t} \equiv -p_{t,I} + \left(\frac{1}{1+r} \right) V'_{t+1,j}(K_{t+1}) = 0$$

The FOC condition above with respect to I_t gives that

$V'_{t+1,j}(K_{t+1}) = (1+r) p_{t,I}$, which also means that $V'_{t,j}(K_t) = (1+r) p_{t-1,I}$

Because

$$\frac{\partial V_{t,j}}{\partial K_t} = p_{t,j} \frac{\partial X_{t,j}}{\partial K_t} + \left(\frac{1}{1+r} \right) \frac{\partial V_{t+1,j}}{\partial K_{t+1}} \frac{\partial K_{t+1}}{\partial K_t} \equiv p_{t,j} \frac{\partial X_{t,j}}{\partial K_t} + \left(\frac{1}{1+r} \right) (1-\delta) V'_{t+1,j}(K_{t+1})$$

Substituting the FOC condition with respect to I_t into the above equation, we obtain the Euler equation

$$(1+r) p_{t-1,I} = p_{t,j} \frac{\partial X_{t,j}}{\partial K_t} + (1-\delta) p_{t,I}$$

Moving the Euler equation one period forward, we get

$$p_{t,I} = \frac{1}{1+r}\left[p_{t+1,j} \frac{\partial X_{t+1,j}}{\partial K_{t+1}} + (1-\delta) p_{t+1,I} \right] \qquad (T-1 \text{ equations})$$

Thus $I_t = K_{t+1} - (1-\delta)K_t$

This condition means that at optimum any feasible reallocation of investment over time can bring zero gain. Rearranging the Euler equation, we have

$$p_{t,I} - \frac{1}{1+r} p_{t+1,j} \frac{\partial X_{t+1,j}}{\partial K_{t+1}} = \frac{1}{1+r}(1-\delta) p_{t+1,I}$$

The left-hand side of the above equation is the net gain of one unit of extra investment made in period t, which equals the difference between the cost of one unit of extra investment ($p_{t,I}$) and the discounted marginal profit of one unit of extra capital accumulated from investment ($\frac{1}{1+r} p_{t+1,j} \frac{\partial X_{t+1,j}}{\partial K_{t+1}}$). The right-hand side simply means the discounted cost of $(1-\delta)$ unit decrease in investment in period $t+1$.

The production is assumed to use the nested CES technology. At top level, aggregate production in each period uses composite intermediate, labour and capital inputs, the demands of which are given at the FOC conditions. The demands for intermediate and labour inputs are static, while the demand for capital is dynamic. It is assumed that substitutability is low between them. At second level, intermediate product is the CES function of agro&aqua-product (aa) and a composite product of energy, industrial product and service (eis). The substitutability between them is also assumed to be low. Given total demand for aggregate intermediate product, minimizing the production cost, we have

$$Z_{t,io} = \min p_{t,aa} X_{t,aa} + p_{t,eis} X_{t,eis}$$

where $X_{t,aa}$ and $X_{t,eis}$ are demands for agro&aqua-product (aa) and a composite product of energy, industrial product and service, respectively. $p_{t,aa}$ and $p_{t,eis}$ are their prices.

Subject to

$$\left(\alpha_{aa}^{\frac{1}{\rho_{io}}} X_{t,aa}^{\frac{\rho_{io}-1}{\rho_{io}}} + \alpha_{eis}^{\frac{1}{\rho_{io}}} X_{t,eis}^{\frac{\rho_{io}-1}{\rho_{io}}} \right)^{\frac{\rho_{io}}{\rho_{io}-1}} = X_{t,io}$$

where α_{aa} and α_{eis} are parameters adjusted to the base year data. ρ_{io} is the elasticity of substitution between $X_{t,aa}$ and $X_{t,eis}$. The Lagrangian for this problem is

$$\Lambda = p_{t,aa} X_{t,aa} + p_{t,eis} X_{t,eis} + \lambda \left(X_{t,io}^{\frac{\rho_{io}-1}{\rho_{io}}} - \alpha_{aa}^{\frac{1}{\rho_{io}}} X_{t,aa}^{\frac{\rho_{io}-1}{\rho_{io}}} - \alpha_{eis}^{\frac{1}{\rho_{io}}}{}_{eis} X_{t,eis}^{\frac{\rho_{io}-1}{\rho_{io}}} \right)$$

The FOCs of this problem are

$$p_{t,aa} - \lambda \alpha_{aa}^{\frac{1}{\rho_{io}}} \left(\frac{\rho_{io}-1}{\rho_{io}} \right) X_{t,aa}^{-\frac{1}{\rho_{io}}} = 0$$

$$p_{t,eis} - \lambda \alpha_{eis}^{\frac{1}{\rho_{io}}} \left(\frac{\rho_{io}-1}{\rho_{io}} \right) X_{t,eis}^{-\frac{1}{\rho_{io}}} = 0$$

$$\alpha_{aa}^{\frac{1}{\rho_{io}}} X_{t,aa}^{\frac{\rho_{io}-1}{\rho_{io}}} + \alpha_{eis}^{\frac{1}{\rho_{io}}} X_{t,eis}^{\frac{\rho_{io}-1}{\rho_{io}}} = X_{t,io}^{\frac{\rho_{io}-1}{\rho_{io}}}$$

Solving for $X_{t,aa}^{\frac{\rho_{io}-1}{\rho_{io}}}$ and $X_{t,eis}^{\frac{\rho_{io}-1}{\rho_{io}}}$, we have

$$X_{t,aa}^{\frac{\rho_{io}-1}{\rho_{io}}} = p_{t,aa}^{-(\rho_{io}-1)} \alpha_{aa}^{\frac{\rho_{io}-1}{\rho_{io}}} \left(\lambda \frac{\rho_{io}-1}{\rho_{io}} \right)^{(\rho_{io}-1)}$$

$$X_{t,eis}^{\frac{\rho_{io}-1}{\rho_{io}}} = p_{t,eis}^{-(\rho_{io}-1)} \alpha_{eis}^{\frac{\rho_{io}-1}{\rho_{io}}} \left(\lambda \frac{\rho_{io}-1}{\rho_{io}} \right)^{(\rho_{io}-1)}$$

Substituting them into constraint condition, we have

$$\alpha_{aa}^{\frac{1}{\rho_{io}}} p_{t,aa}^{-(\rho_{io}-1)} \alpha_{aa}^{\frac{\rho_{io}-1}{\rho_{io}}} \left(\lambda \frac{\rho_{io}-1}{\rho_{io}} \right)^{(\rho_{io}-1)} + \alpha_{eis}^{\frac{1}{\rho_{io}}} p_{t,eis}^{-(\rho_{io}-1)} \alpha_{eis}^{\frac{\rho_{io}-1}{\rho_{io}}} \left(\lambda \frac{\rho_{io}-1}{\rho_{io}} \right)^{(\rho_{io}-1)} = X_{t,io}^{\frac{\rho_{io}-1}{\rho_{io}}}$$

$$\left(\lambda \frac{\rho_{io}-1}{\rho_{io}} \right)^{(\rho_{io}-1)} \left(p_{t,aa}^{-(\rho_{io}-1)} \alpha_{aa} + p_{t,eis}^{-(\rho_{io}-1)} \alpha_{eis} \right) = X_{t,io}^{\frac{\rho_{io}-1}{\rho_{io}}}$$

$$\left(\lambda \frac{\rho_{io}-1}{\rho_{io}} \right)^{(\rho_{io}-1)} = X_{t,io}^{\frac{\rho_{io}-1}{\rho_{io}}} \left(p_{t,aa}^{-(\rho_{io}-1)} \alpha_{aa} + p_{t,eis}^{-(\rho_{io}-1)} \alpha_{eis} \right)^{-1}$$

Substituting $\left(\lambda \frac{\rho_{io}-1}{\rho_{io}} \right)^{(\rho_{io}-1)}$ into the solution equations above for $X_{t,aa}$ and $X_{t,eis}$, we get

$$X_{t,aa}^{\frac{\rho_{io}-1}{\rho_{io}}} = p_{t,aa}^{-(\rho_{io}-1)} \alpha_{aa}^{\frac{\rho_{io}-1}{\rho_{io}}} X_{t,io}^{\frac{\rho_{io}-1}{\rho_{io}}} \left(p_{t,aa}^{-(\rho_{io}-1)} \alpha_{aa} + p_{t,eis}^{-(\rho_{io}-1)} \alpha_{eis} \right)^{-1}$$

$$X_{t,eis}^{\frac{\rho_{io}-1}{\rho_{io}}} = p_{t,eis}^{-(\rho_{io}-1)} \alpha_{eis}^{\frac{\rho_{io}-1}{\rho_{io}}} X_{t,io}^{\frac{\rho_{io}-1}{\rho_{io}}} \left(p_{t,aa}^{-(\rho_{io}-1)} \alpha_{aa} + p_{t,eis}^{-(\rho_{io}-1)} \alpha_{eis} \right)^{-1}$$

$$X_{t,aa} = \alpha_{aa} X_{t,io} \left(\frac{p_{t,io}}{p_{t,aa}} \right)^{\rho_{io}} \qquad \text{(1 equation)}$$

$$X_{t,eis} = \alpha_{eis} X_{t,io} \left(\frac{p_{t,io}}{p_{t,eis}} \right)^{\rho_{io}} \qquad \text{(1 equation)}$$

where $p_{t,io} = \left(p_{t,aa}^{-(\rho_{io}-1)} \alpha_{aa} + p_{t,eis}^{-(\rho_{io}-1)} \alpha_{eis} \right)^{-\frac{1}{\rho_{io}-1}}$ by duality.

Further down to second level of production, given $X_{t,aa}$ and $X_{t,eis}$, minimizing the production cost, we have

$$Z_{t,aa} = \min p_{t,agr} X_{t,agr} + p_{t,aqu} X_{t,aqu}$$

where $X_{t,agr}$ and $X_{t,aqu}$ are demands for agri-product (agr) and aqua-product (aqu), respectively. $p_{t,agr}$ and $p_{t,aqu}$ are their prices.

Subject to

$$\left(\alpha_{agr}^{\frac{1}{\rho_{aa}}} X_{t,agr}^{\frac{\rho_{aa}-1}{\rho_{aa}}} + \alpha_{aqu}^{\frac{1}{\rho_{aa}}} X_{t,aqu}^{\frac{\rho_{aa}-1}{\rho_{aa}}} \right)^{\frac{\rho_{aa}}{\rho_{aa}-1}} = X_{t,aa}$$

where α_{agr} and α_{aqu} are parameters adjusted to the base year data. ρ_{aa} is the elasticity of substitution between $X_{t,agr}$ and $X_{t,aqu}$. The conditional demand functions of this problem are

$$X_{t,agr} = \alpha_{agr} X_{t,aa} \left(\frac{p_{t,aa}}{p_{t,agr}} \right)^{\rho_{aa}} \quad \text{(1 equation)}$$

$$X_{t,aqu} = \alpha_{aqu} X_{t,aa} \left(\frac{p_{t,aa}}{p_{t,aqu}} \right)^{\rho_{aa}} \quad \text{(1 equation)}$$

Similar for $X_{t,eis}$, we have

$$Z_{t,eis} = \min p_{t,eng} X_{t,eng} + p_{t,ind} X_{t,ind} + p_{t,sev} X_{t,sev}$$

where $X_{t,eng}$, $X_{t,ind}$ and $X_{t,sev}$ are demands for energy, industrial product, and service, respectively. $p_{t,eng}$, $p_{t,ind}$ and $p_{t,sev}$ are their prices.

Subject to

$$\left(\alpha_{eng}^{\frac{1}{\rho_{eis}}} X_{t,eng}^{\frac{\rho_{eis}-1}{\rho_{eis}}} + \alpha_{ind}^{\frac{1}{\rho_{eis}}} X_{t,ind}^{\frac{\rho_{eis}-1}{\rho_{eis}}} + \alpha_{sev}^{\frac{1}{\rho_{eis}}} X_{t,sev}^{\frac{\rho_{eis}-1}{\rho_{eis}}} \right)^{\frac{\rho_{eis}}{\rho_{eis}-1}} = X_{t,eis}$$

where $\alpha_{t,eng}$, $\alpha_{t,ind}$ and $\alpha_{t,sev}$ are parameters adjusted to the base year data. ρ_{eis} is the elasticity of substitution between $X_{t,eng}$, $X_{t,ind}$ and $X_{t,sev}$. The conditional demand functions of this problem are

$$X_{t,eng} = \alpha_{eng} X_{t,eis} \left(\frac{p_{t,eis}}{p_{t,eng}} \right)^{\rho_{eis}} \quad \text{(1 equation)}$$

$$X_{t,ind} = \alpha_{ind} X_{t,eis} \left(\frac{p_{t,eis}}{p_{t,ind}} \right)^{\rho_{eis}} \quad \text{(1 equation)}$$

$$X_{t,sev} = \alpha_{sev} X_{t,eis} \left(\frac{p_{t,eis}}{p_{t,sev}} \right)^{\rho_{eis}} \quad \text{(1 equation)}$$

2.1.3.2.2 Fish harvest producers

The model distinguishes a number of different fish harvesters by métier, which is defined as a specific fleet equipping with a specific gear, targeting a specific species and including other species as by-products. Assume investment in harvest sector is exogenous subject to policy interventions. Thus, a representative métier (Appendix 1*C*) maximizes its intertemporal profit for a particular duration of time subject to intertemporal constraint of biomass change

$$V_{har,j} = \max \sum_{t=1}^{T} (1+r)^{-t} \begin{pmatrix} p_{t,j} Y_{t,j} - p_{t,aqu} X_{t,aqu} - p_{t,agr} X_{t,agr} \\ - p_{t,eng} X_{t,eng} - p_{t,ind} X_{t,ind} - p_{t,sev} X_{t,sev} - w_t L_t - p_{t,I} I_t \end{pmatrix}, \quad j \in (1 \ldots mt)$$

where har and sp_1 indicate harvest and the harvested species, respectively. $Y_{t,j}$ is métier j's harvest activity, which produces multiple species of fishes, $X_{t,i,j}, i \in (1...sp_1)\ and\ j \in (1...mt)$. mt is the number of métiers or harvesters, which includes small-scale fisher. For the input terms in above equation, we omit the subscript j. Assuming the harvest activity uses a nearly Leontief technology, we approximate it with the CES function with a very small elasticity of substitution

$$Y_{t,j} = \left(\begin{array}{l} \alpha_{aqu}^{\frac{1}{\rho_{har}}} X_{t,aqu}^{\frac{\rho_{har}-1}{\rho_{har}}} + \alpha_{agr}^{\frac{1}{\rho_{har}}} X_{t,agr}^{\frac{\rho_{har}-1}{\rho_{har}}} + \alpha_{eng}^{\frac{1}{\rho_{har}}} X_{t,eng}^{\frac{\rho_{har}-1}{\rho_{har}}} \\ + \alpha_{ind}^{\frac{1}{\rho_{har}}} X_{t,ind}^{\frac{\rho_{har}-1}{\rho_{har}}} + \alpha_{sev}^{\frac{1}{\rho_{har}}} X_{t,sev}^{\frac{\rho_{har}-1}{\rho_{har}}} + \alpha_{l}^{\frac{1}{\rho_{har}}} L_{t}^{\frac{\rho_{har}-1}{\rho_{har}}} + \alpha_{k}^{\frac{1}{\rho_{har}}} K_{t}^{\frac{\rho_{har}-1}{\rho_{har}}} \end{array} \right)^{\frac{\rho_{har}}{\rho_{har}-1}}$$

The harvested fishes can be computed through

$$X_{t,i,j} = \theta_{t,i,j} Y_{t,j}, \quad i \in (1...sp_1),\ j \in (1...mt)$$

where $\theta_{t,i,j}$ is the CPUE (catch per unit of effort) variable in the terminology of fisheries economics. In the model this is an endogenous variable and defined as

$$\theta_{t,i,j} = \theta_{t-1,i,j} \frac{BM_{t.i,j}}{BM_{t-1,i,j}}, \quad i \in (1...sp_1),\ j \in (1...mt) \qquad \text{(1 equation)}$$

where $BM_{t,i,j}$ is the biomass stock of species i available for métier j's harvest activity. It is the amount of total biomass deducted the catches by other métiers in current period. That is

$$BM_{t,i,j} = BM_{t,i} - \sum_{h=1}^{mt} X_{t,i,h}, \quad h \neq j$$

Total biomass of species i depends on natural growth of the biomass and total catch in previous period. Biomass growth can be computed based on simply assumed functions such as linear, logistic, exponential, or others. The biomass change can also be assessed from comprehensive biological model systems where biological interactions are taken into account to a considerable extent. Here, we provisionally assume biomass grows according to a logistic function. In future research the model can be linked with biological model to assess biomass growth.

For the logistic growth of biomass

$$BM_{t,i} = BM_{t-1,i} + \varphi_i \left(1 - \frac{BM_{t-1,i}}{K_i}\right) BM_{t-1,i} - \sum_{j=1}^{mt} X_{t-1,i,j}, \quad i \in (1...sp_1)$$

where $\varphi_{t,i}$ is the growth rate of biomass, φ_i the instantaneous growth rate parameter, and K_i the environmental carrying capacity parameter of species i. The third term in right-hand side is total catch per species, a summing up across all metiers. Assume each metier takes other metiers' decision as given. Substituting $BM_{t,i}$ into $BM_{t,i,j}$, we have

$$BM_{t,i,j} = BM_{t,i} - \sum_{h=1}^{mt} X_{t,i,h}$$

$$= (1 + \varphi_{t,i}) BM_{t-1,i} - \sum_{j=1}^{mt} X_{t-1,i,j} - \sum_{h=1}^{mt} X_{t,i,h}, \quad i \in (1...sp_1), h \neq j$$

Moving one period forward, we get

$$BM_{t+1,i,j} = \left(1+\varphi_i\left(1-\frac{BM_{t,i}}{K_i}\right)\right)BM_{t,i} - \sum_{j=1}^{mt}\theta_{t,i,j}Y_{t,j} - \sum_{h=1}^{mt}\theta_{t+1,i,h}Y_{t+1,j}, \quad i \in (1 \ldots sp_1), h \neq j$$

Maximizing the objective function subject to the above constraints where $BM_{t,i,j}$ and $Y_{t,j}$ are the state and control variables, respectively, we have the following Bellman recursive equation

$$V_{t,j} = \max \sum_{t=1}^{T}(1+r)^{-t}\begin{pmatrix} p_{t,j}Y_{t,j} - p_{t,aqu}X_{t,aqu} - p_{t,agr}X_{t,agr} - p_{t,eng}X_{t,eng} \\ - p_{t,ind}X_{t,ind} - p_{t,sev}X_{t,sev} - w_tL_t - p_{t,I}I_t \end{pmatrix}$$

$$= \max\begin{bmatrix} \sum_{i=1}^{sp_1} p_{t,i}X_{t,i,j} - p_{t,aqu}X_{t,aqu} - p_{t,agr}X_{t,agr} - p_{t,eng}X_{t,eng} \\ - p_{t,ind}X_{t,ind} - p_{t,sev}X_{t,sev} - w_tL_t - p_{t,I}I_t + \left(\frac{1}{1+r}\right)V_{t+1,j}(BM_{t+1}) \end{bmatrix}$$

The FOCs give the following equations

$$X_{t,aqu} = \alpha_{aqu}Y_{t,j}\left(\frac{p_{t,j}}{p_{t,aqu}}\right)^{\rho_j}$$ (1 equation)

$$X_{t,agr} = \alpha_{agr}Y_{t,j}\left(\frac{p_{t,j}}{p_{t,agr}}\right)^{\rho_j}$$ (1 equation)

$$X_{t,eng} = \alpha_{eng}Y_{t,j}\left(\frac{p_{t,j}}{p_{t,eng}}\right)^{\rho_j}$$ (1 equation)

$$X_{t,ind} = \alpha_{ind}Y_{t,j}\left(\frac{p_{t,j}}{p_{t,ind}}\right)^{\rho_j}$$ (1 equation)

$$X_{t,sev} = \alpha_{sev}Y_{t,j}\left(\frac{p_{t,j}}{p_{t,sev}}\right)^{\rho_j}$$ (1 equation)

$$L_t = \alpha_l Y_{t,j}\left(\frac{p_{t,j}}{w_t}\right)^{\rho_j}$$ (1 equation)

$$K_t = \alpha_k Y_{t,j}\left(\frac{p_{t,j}}{r_t}\right)^{\rho_j}$$ ($T-1$ equations)

$$p_{t,j} + \left(\frac{1}{1+r}\right) V'_{t+1,j}\left(BM_{t+1,i,j}\right) \frac{\partial BM_{t+1,i,j}}{\partial Y_{t,j}}$$

$$\equiv p_{t,j} + \left(\frac{1}{1+r}\right) V'_{t+1,j}\left(BM_{t+1,i,j}\right)\left(-\theta_{t-1,i,j}\frac{BM_{t.i,j}}{BM_{t-1,i,j}}\right) = 0$$

(sp_1 equations)

$$\Rightarrow V'_{t+1,j}\left(BM_{t+1,i,j}\right) = \frac{(1+r)p_{t,j}}{\theta_{t,i,j}}$$

$$\Rightarrow V'_{t,j}\left(BM_{t,i,j}\right) = \frac{(1+r)p_{t-1,j}}{\theta_{t-1,i,j}}$$

$$\frac{\partial V_{t,har}}{\partial BM_{t,i,j}} = p_{t,j}\frac{\partial Y_{t,j}}{\partial BM_{t,i,j}} + \left(\frac{1}{1+r}\right)\frac{\partial V_{t+1,har}}{\partial BM_{t+1,i,j}}\frac{\partial BM_{t+1,i,j}}{\partial BM_{t,i,j}}$$

$$\equiv p_{t,j}\frac{\partial Y_{t,j}}{\partial BM_{t,i,j}} + \left(\frac{1}{1+r}\right)\left(1+\varphi_i\left(1-\frac{2BM_{t,i,j}}{K_i}\right) - \frac{\theta_{t-1,i,j}}{BM_{t-1,i,j}}Y_{t,j} - \frac{\theta_{t-1,i,j}}{BM_{t-1,i,j}}BM_{t,i,j}\frac{\partial Y_{t,j}}{\partial BM_{t,i,j}}\right)V'_{t+1,har}\left(BM_{t+1,i,j}\right)$$

Substituting the FOC condition with respect to $Y_{t,j}$ into the above equation, we obtain the Euler equation

$$\frac{(1+r)p_{t-1,j}}{\theta_{t-1,i,j}} = p_{t,j}\frac{\partial Y_{t,j}}{\partial BM_{t,i,j}} + \left(1+\varphi_i\left(1-\frac{2BM_{t,i,j}}{K_i}\right) - \frac{\theta_{t-1,i,j}}{BM_{t-1,i,j}}Y_{t,j} - \frac{\theta_{t-1,i,j}}{BM_{t-1,i,j}}BM_{t,i,j}\frac{\partial Y_{t,j}}{\partial BM_{t,i,j}}\right)\frac{p_{t,j}}{\theta_{t,i,j}}$$

Moving the equation one period forward, we get

$$BM_{t+1,i,j} = \frac{p_{t+1,j}}{(1+r)p_{t,j}}\left[\left(1+\varphi_i\left(1-\frac{2BM_{t,i,j}}{K_i}\right)\right)BM_{t,i,j} - \theta_{t,i,j}Y_{t+1,j}\right]$$

The above condition states that taking all other fishing activities as given the activity j's marginal costs will be equivalent in long-run equilibrium, $\frac{p_{t+1,j}}{(1+r)p_{t,j}} = 1$, if the activity remains constant over time, $Y_{t+1,j} = Y_{t,j}$. However, if the activity is intensified, $Y_{t+1,j} > Y_{t,j}$, its long-run equilibrium marginal costs will be higher than before, $\frac{p_{t+1,j}}{(1+r)p_{t,j}} > 1$.

2.1.3.2.3 Aquaculture producers

Aquaculture is regarded to consist of a number of different producers, each of which represents a group of identical individual producers and specializes in a single species of fish subject to a nearly Leontief technology. A representative aquaculture producer maximizes her intertemporal profit for a particular duration of time subject to intertemporal constraint of capital accumulation

$$V_{acu,j} = \max\sum_{t=1}^{T}(1+r)^{-t}\begin{pmatrix} p_{t,j}X_{t,j} - p_{t,aqu,sp_2}X_{t,aqu,sp_2} - p_{t,agr}X_{t,agr} \\ -p_{t,eng}X_{t,eng} - p_{t,ind}X_{t,ind} - p_{t,sev}X_{t,sev} - w_tL_t - p_{t,I}I_t \end{pmatrix}, \quad j \in (1 \ldots sp_2)$$

where acu and sp_2 indicate aquaculture and the species of output, respectively.

Subject to

$K_{t+1} = (1-\delta)K_t + I_t$, and K_1, K_T given

where K_t is capital stock in the aquaculture sector. We approximate the nearly Leontief technology with the CES function with a very small elasticity of substitution

$$X_{t,j} = \left(\alpha_{aqu}^{\frac{1}{\rho_{acu}}} X_{t,aqu}^{\frac{\rho_{acu}-1}{\rho_{acu}}} + \alpha_{agr}^{\frac{1}{\rho_{acu}}} X_{t,agr}^{\frac{\rho_{acu}-1}{\rho_{acu}}} + \alpha_{eng}^{\frac{1}{\rho_{acu}}} X_{t,eng}^{\frac{\rho_{acu}-1}{\rho_{acu}}} + \alpha_{ind}^{\frac{1}{\rho_{acu}}} X_{t,ind}^{\frac{\rho_{acu}-1}{\rho_{acu}}} + \alpha_{sev}^{\frac{1}{\rho_{acu}}} X_{t,sev}^{\frac{\rho_{acu}-1}{\rho_{acu}}} + \alpha_{l}^{\frac{1}{\rho_{acu}}} L_{t}^{\frac{\rho_{acu}-1}{\rho_{acu}}} + \alpha_{k}^{\frac{1}{\rho_{acu}}} K_{t}^{\frac{\rho_{acu}-1}{\rho_{acu}}} \right)^{\frac{\rho_{acu}}{\rho_{acu}-1}}$$

The production demands are

$$X_{t,aqu} = \alpha_{aqu} X_{t,j} \left(\frac{p_{t,j}}{p_{t,aqu}} \right)^{\rho_j} \qquad \text{(1 equation)}$$

$$X_{t,agr} = \alpha_{agr} X_{t,j} \left(\frac{p_{t,j}}{p_{t,agr}} \right)^{\rho_j} \qquad \text{(1 equation)}$$

$$X_{t,eng} = \alpha_{eng} X_{t,j} \left(\frac{p_{t,j}}{p_{t,eng}} \right)^{\rho_j} \qquad \text{(1 equation)}$$

$$X_{t,ind} = \alpha_{ind} X_{t,j} \left(\frac{p_{t,j}}{p_{t,ind}} \right)^{\rho_j} \qquad \text{(1 equation)}$$

$$X_{t,sev} = \alpha_{sev} X_{t,j} \left(\frac{p_{t,j}}{p_{t,sev}} \right)^{\rho_j} \qquad \text{(1 equation)}$$

$$L_t = \alpha_l X_{t,j} \left(\frac{p_{t,j}}{w_t} \right)^{\rho_j} \qquad \text{(1 equation)}$$

$$K_{t+1} = \alpha_k X_{t+1,j} \left(\frac{p_{t+1,j}}{(1+r)p_{t,I} - (1-\delta)p_{t+1,I}} \right)^{\rho_j} \qquad (T-1 \text{ equations})$$

2.1.3.2.4 Fishery business service producers

The representative fishery business service producer is assumed to provide a single service to harvesters and maximizes her intertemporal profit for a particular duration of time subject to intertemporal constraint of capital accumulation

$$V_{fbs} = \max \sum_{t=1}^{T} (1+r)^{-t} \left(p_{t,fbs} X_{t,fbs} - p_{t,eng} X_{t,eng} - p_{t,ind} X_{t,ind} - p_{t,sev} X_{t,sev} - w_t L_t - p_{t,I} I_t \right)$$

where *fbs* indicates the fishery business service sector, $X_{t,fbs}$, $X_{t,eng}$, $X_{t,ind}$, $X_{t,sev}$, L_t, and I_t now represents the producer's output, intermediate inputs of energy, industrial product and general service, labour and investment, respectively. We assume there are no intermediate inputs of agricultural or aquatic products for the service production.

Subject to

$K_{t+1} = (1-\delta)K_t + I_t$, and K_1, K_T given where K_t is capital stock in the fishery business service sector. Assuming the service production uses a nearly Leontief technology, we approximate it with a CES function with very small elasticity of substitution

$$X_{t,fbs} = \left(\alpha_{eng}^{\frac{1}{\rho_{fbs}}} X_{t,eng}^{\frac{\rho_{fbs}-1}{\rho_{fbs}}} + \alpha_{ind}^{\frac{1}{\rho_{fbs}}} X_{t,ind}^{\frac{\rho_{fbs}-1}{\rho_{fbs}}} + \alpha_{sev}^{\frac{1}{\rho_{fbs}}} X_{t,sev}^{\frac{\rho_{fbs}-1}{\rho_{fbs}}} + \alpha_{l}^{\frac{1}{\rho_{fbs}}} L_{t}^{\frac{\rho_{fbs}-1}{\rho_{fbs}}} + \alpha_{k}^{\frac{1}{\rho_{fbs}}} K_{t}^{\frac{\rho_{fbs}-1}{\rho_{fbs}}} \right)^{\frac{\rho_{fbs}}{\rho_{fbs}-1}}$$

$$X_{t,eng} = \alpha_{eng} X_{t,fbs} \left(\frac{p_{t,fbs}}{p_{t,eng}} \right)^{\rho_{fbs}} \qquad \text{(1 equation)}$$

$$X_{t,ind} = \alpha_{ind} X_{t,fbs} \left(\frac{p_{t,fbs}}{p_{t,ind}} \right)^{\rho_{fbs}} \qquad \text{(1 equation)}$$

$$X_{t,sev} = \alpha_{sev} X_{t,fbs} \left(\frac{p_{t,fbs}}{p_{t,sev}} \right)^{\rho_{fbs}} \qquad \text{(1 equation)}$$

$$L_t = \alpha_l X_{t,fbs} \left(\frac{p_{t,fbs}}{w_t} \right)^{\rho_{fbs}} \qquad \text{(1 equation)}$$

$$K_{t+1} = \alpha_k X_{t+1,fbs} \left(\frac{p_{t+1,fbs}}{(1+r)p_{t,I} - (1-\delta)p_{t+1,I}} \right)^{\rho_{fbs}} \qquad (T-1 \text{ equations})$$

2.1.3.2.5 Fish processing producers

The fish processing production is assumed to be a two-level nested system (Appendix *D*), providing multiple aqua-products. The representative fish processing producer maximizes her intertemporal profit for a particular duration of time subject to intertemporal constraint of capital accumulation

$$V_{pro} = \max \sum_{t=1}^{T} (1+r)^{-t} \left(p_{t,pro} Y_{t,pro} - p_{t,tbp} X_{t,tbp} - p_{t,eng} X_{t,eng} - p_{t,ind} X_{t,ind} - p_{t,sev} X_{t,sev} - w_t L_t - p_{t,I} I_t \right)$$

$$= \max \sum_{t=1}^{T} (1+r)^{-t} \left(\sum_{i=1}^{sp_3} p_{t,i,pro} X_{t,i,pro} - p_{t,tbp} X_{t,tbp} - p_{t,eng} X_{t,eng} - p_{t,ind} X_{t,ind} - p_{t,sev} X_{t,sev} - w_t L_t - p_{t,I} I_t \right)$$

where pro and tbp indicate the processed and to be processed aqua-products, respectively. $Y_{t,pro}$ is the sector's activity, which produces multiple products, $X_{t,i,pro}, i \in (1...sp_3)$ where sp_3 indicates the types of processed products that correspond to the species of raw fish processed. Assume there are no intermediate inputs of agricultural products for the processing activity.

Subject to

$K_{t+1} = (1-\delta)K_t + I_t$, and K_1, K_T given

where K_t is capital stock in the processing sector. Assuming the processing activity uses a nearly Leontief technology, we approximate it with the CES function with a very small elasticity of substitution

$$Y_{t,pro} = \left(\alpha_{tbp}^{\frac{1}{\rho_{pro}}} X_{t,tbp}^{\frac{\rho_{pro}-1}{\rho_{pro}}} + \alpha_{eng}^{\frac{1}{\rho_{pro}}} X_{t,eng}^{\frac{\rho_{pro}-1}{\rho_{pro}}} + \alpha_{ind}^{\frac{1}{\rho_{pro}}} X_{t,ind}^{\frac{\rho_{pro}-1}{\rho_{pro}}} + \alpha_{sev}^{\frac{1}{\rho_{pro}}} X_{t,sev}^{\frac{\rho_{pro}-1}{\rho_{pro}}} + \alpha_{l}^{\frac{1}{\rho_{pro}}} L_{t}^{\frac{\rho_{pro}-1}{\rho_{pro}}} + \alpha_{k}^{\frac{1}{\rho_{pro}}} K_{t}^{\frac{\rho_{pro}-1}{\rho_{pro}}} \right)^{\frac{\rho_{pro}}{\rho_{pro}-1}}$$

The production demands are

$$X_{t,tbp} = \alpha_{tbp} Y_{t,pro} \left(\frac{p_{t,pro}}{p_{t,tbp}} \right)^{\rho_{pro}}$$ (1 equation)

$$X_{t,eng} = \alpha_{eng} Y_{t,pro} \left(\frac{p_{t,pro}}{p_{t,eng}} \right)^{\rho_{pro}}$$ (1 equation)

$$X_{t,ind} = \alpha_{ind} Y_{t,pro} \left(\frac{p_{t,pro}}{p_{t,ind}} \right)^{\rho_{pro}}$$ (1 equation)

$$X_{t,sev} = \alpha_{sev} Y_{t,pro} \left(\frac{p_{t,pro}}{p_{t,sev}} \right)^{\rho_{pro}}$$ (1 equation)

$$L_{t} = \alpha_{l} Y_{t,pro} \left(\frac{p_{t,pro}}{w_{t}} \right)^{\rho_{pro}}$$ (1 equation)

$$K_{t+1} = \alpha_{k} Y_{t+1,pro} \left(\frac{p_{t+1}}{(1+r)p_{t,I} - (1-\delta)p_{t+1,I}} \right)^{\rho_{pro}}$$ ($T-1$ equations)

At next level of the production, $X_{t,tbp}$ is disaggregated according to the CES technology

$$X_{t,tbp} = \left(\sum_{i=1}^{sp_3} \alpha_i^{\frac{1}{\rho_{tbp}}} X_{t,i,tbp}^{\frac{\rho_{tbp}-1}{\rho_{tbp}}} \right)^{\frac{\rho_{tbp}}{\rho_{tbp}-1}}, \quad i \in (1 \ldots sp_3)$$

where sp_3 indicates the species of fishes to be processed. Here we give the elasticity of substitution between different species, ρ_{aqu}, a very large value to approximate a nearly perfect substitution technology. The demand for each species of raw fishes to be processed thus is

$$X_{t,i,tbp} = \alpha_i X_{t,tbp} \left(\frac{p_{t,tbp}}{p_{t,i}} \right)^{\rho_{tbp}}, \quad i \in (1 \ldots sp_3)$$ (sp_3 equations)

Assume a fixed proportion of each species of the raw fishes to be processed can be processed into the processed aqua-products, we can directly obtain the output of each processed aqua-products by

$$X_{t,i,pro} = \vartheta_i X_{t,i,tbp}, \quad i \in (1 \ldots sp_3)$$

Thus

$$Y_{t,pro} = \sum_{i=1}^{sp_3} X_{t,i,pro}, \quad i \in (1 \ldots sp_3)$$ (1 equation)

2.1.4 Government account

Government collects its revenues from various taxes, levies and tariffs:

$$G_{t,R} = \sum taxes$$

Government saves a fixed proportion of its total revenue:

$$G_{t,S} = \theta_S G_{t,R}$$

Government's total expenditure is the difference between total revenue and savings: $G_{t,E} = G_{t,R} - G_{t,S}$

Government may transfer some revenues to households, firms or abroad:

$$G_{t,T} = 0$$

Government's aggregate consumption: $G_{t,C} = G_{t,E} - G_{t,T}$

Government disaggregate consumption:

$$G_{t,i,C} = \theta_{i,C} G_{t,C}\,,\; i \in \left(agr, eng, ind, sev, aqu, sp_1, sp_2, sp_3, sp\right)$$

where $G_{t,R}$, $G_{t,S}$, $G_{t,E}$, $G_{t,T}$, and $G_{t,C}$ are government's total revenues, savings, expenditures, transfers, and consumption, respectively. θ_S is fixed proportion of savings in total government revenues. $\theta_{i,C}$ are fixed proportions of consumption commodities in total government consumption.

2.1.5 Capital account

Investment is assumed to come from savings, which include both households and government savings.

Total savings (SV_t) = household savings (S_t) + government savings ($G_{t,S}$)

Total investment is disaggregated into investment by product according to fixed, observed investment composition:

Total investment: $I_t = \sum_j I_{t,j}\,,\; j \in \left(agr, eng, ind, sev, mt, pro\right)$

Disaggregate investment:

$I_{t,i,j} = \theta_{i,j,I} I_{t,j}\,,\; i \in \left(agr, eng, ind, sev, aqu, sp_1, sp_3, sp\right)$ and $j \in \left(agr, eng, ind, sev, mt, pro\right)$

where are fixed proportions of each category of investment commodities in total investment.

Net foreign investment: $NFK_t = SV_t - I_t$

2.1.6 Commodity markets

2.1.6.1 Consumers' composite and final demands

At top level, aggregate consumption over time

Composite commodity: $C_t = \sum_{h=1}^{6} c_{t,h} N_{t,h}$

where C_t is total aggregate consumption, $c_{t,h}$ and $N_{t,h}$ are per capita aggregate consumption and population of household h, respectively.

At second level, we have

Composite commodity: $C_{t,aa} = \sum_{h=1}^{6} c_{t,aa,h} N_{t,h}$

Real commodities: $C_{t,eng} = \sum_{h=1}^{6} c_{t,eng,h} N_{t,h}$, $C_{t,ind} = \sum_{h=1}^{6} c_{t,ind,h} N_{t,h}$, $C_{t,sev} = \sum_{h=1}^{6} c_{t,sev,h} N_{t,h}$

At third level, we have

Real commodities: $C_{t,agr} = \sum_{h=1}^{6} c_{t,agr,h} N_{t,h}$, $C_{t,aqu} = \sum_{h=1}^{6} c_{t,aqu,h} N_{t,h}$

At fourth level, we have

Composite commodity: $C_{t,lu} = \sum_{h=1}^{6} c_{t,lu,h} N_{t,h}$, $C_{t,ba} = \sum_{h=1}^{6} c_{t,ba,h} N_{t,h}$

At fifth level, we have

Composite commodity: $C_{t,lu,rf} = \sum_{h=1}^{6} c_{t,lu,rf,h} N_{t,h}$, $C_{t,lu,pf} = \sum_{h=1}^{6} c_{t,lu,pf,h} N_{t,h}$,

$C_{t,ba,rf} = \sum_{h=1}^{6} c_{t,ba,rf,h} N_{t,h}$, $C_{t,ba,pf} = \sum_{h=1}^{6} c_{t,ba,pf,h} N_{t,h}$

At bottom level, we have

Real commodities: $C_{t,i,lu,rf} = \sum_{h=1}^{6} c_{t,i,lu,rf,h} N_{t,h}$, $C_{t,i,ba,rf} = \sum_{h=1}^{6} c_{t,i,ba,rf,h} N_{t,h}$, $i \in (1 ... sp)$

$C_{t,j,lu,pf} = \sum_{h=1}^{6} c_{t,j,lu,pf,h} N_{t,h}$, $C_{t,j,ba,pf} = \sum_{h=1}^{6} c_{t,j,ba,pf,h} N_{t,h}$, $j \in (1 ... sp_3)$

$C_{t,i,rf} = C_{t,i,lu,rf} + C_{t,i,ba,rf}$

$C_{t,j,pf} = C_{t,j,lu,pf} + C_{t,j,ba,pf}$

Government's consumption demands

$G_{t,i,C}$, $i \in (agr, eng, ind, sev, aqu, sp_1, sp_2, sp_3, sp)$

Investment demands

$I_{t,i,j}$, $i \in (agr, eng, ind, sev, aqu, sp_1, sp_2, sp_3, sp)$ and $j \in (agr, eng, ind, sev, mt, sp_2, fbs, pro, maq)$

2.1.6.2 Producers' intermediate demands

For general producers

Composite commodity: $X_{t,io,j}$, $j \in (agr, eng, ind, sev)$

Composite commodity: $X_{t,aa,j}$, $X_{t,eis,j}$, $j \in (agr, eng, ind, sev)$

Real commodities: $X_{t,agr,j}$, $X_{t,aqu,j}$, $j \in (agr, eng, ind, sev)$

Real commodities: $X_{t,eng,j}$, $X_{t,ind,j}$, $X_{t,sev,j}$, $j \in (agr, eng, ind, sev)$

For fishery harvest producers

Real commodities: $X_{t,aqu,j}$, $X_{t,fbs,j}$, $X_{t,agr,j}$, $X_{t,eng,j}$, $X_{t,ind,j}$, $X_{t,sev,j}$, $j \in (1...mt)$

For fishery processing sector

Composite commodity: $X_{t,tbp,pro}$

Real commodities: $X_{t,eng,pro}$, $X_{t,ind,pro}$, $X_{t,sev,pro}$, $X_{t,i,pro}$, $i \in (1...sp_3)$

2.1.6.3 Total demands (closed economy)

Real commodities:

$$X_{t,agr}^{D} = X_{t,agr,agr} + X_{t,agr,eng} + X_{t,agr,ind} + X_{t,agr,sev} + \sum_{j=1}^{mt} X_{t,agr,j}$$

$$+ C_{t,agr} + G_{t,agr,C} + \sum_{j} I_{t,agr,j},\ j \in (agr, eng, ind, sev, mt, pro)$$

$$X_{t,eng}^{D} = X_{t,eng,agr} + X_{t,eng,eng} + X_{t,eng,ind} + X_{t,eng,sev} + \sum_{j=1}^{mt} X_{t,eng,j} + X_{t,eng,pro}$$

$$+ C_{t,eng} + G_{t,eng,C} + \sum_{j} I_{t,eng,j},\ j \in (agr, eng, ind, sev, mt, pro)$$

$$X_{t,ind}^{D} = X_{t,ind,agr} + X_{t,ind,eng} + X_{t,ind,ind} + X_{t,ind,sev} + \sum_{j=1}^{mt} X_{t,ind,j} + X_{t,ind,pro}$$

$$+ C_{t,ind} + G_{t,ind,C} + \sum_{j} I_{t,ind,j},\ j \in (agr, eng, ind, sev, mt, pro)$$

$$X_{t,sev}^{D} = X_{t,sev,agr} + X_{t,sev,eng} + X_{t,sev,ind} + X_{t,sev,sev} + \sum_{j=1}^{mt} X_{t,sev,j} + X_{t,sev,pro}$$

$$+ C_{t,sev} + G_{t,sev,C} + \sum_{j} I_{t,sev,j},\ j \in (agr, eng, ind, sev, mt, pro)$$

$$X_{t,i,rf,har}^{D} = X_{t,i,tbp,pro} + C_{t,i,rf}\ ,\ i \in (1...sp_1)$$

$$X_{t,i,pf,pro}^{D} = C_{t,i,pf}\ ,\ i \in (1...sp_3)$$

Composite commodity:

$$X_{t,aqu}^{D} = X_{t,aqu,agr} + X_{t,aqu,eng} + X_{t,aqu,ind} + X_{t,aqu,sev} + \sum_{j=1}^{mt} X_{t,aqu,j}$$

2.1.6.4 Producers' supply

Real commodities:

$$X_{t,agr}^{S} = X_{t,agr}$$

$$X_{t,eng}^{S} = X_{t,eng}$$

$$X^S_{t,ind} = X_{t,ind}$$

$$X^S_{t,sev} = X_{t,sev}$$

$$X^S_{t,i,rf,har} = X_{t,i,rf,har}\ ,\ i \in (1 \ldots sp_1)$$

$$X^S_{t,i,pf,pro} = X_{t,i,pf,pro}\ ,\ i \in (1 \ldots sp_3)$$

Composite commodity:

$$X^S_{t,aqu} = \theta_{aqu} X^S_{t,rf}$$

2.1.6.5 The open economy

Total demand:

$$X^D_{t,j} = \left(\alpha_{XD,j}^{\frac{1}{\rho_j}} XD_{t,j}^{\frac{\rho_j - 1}{\rho_j}} + \alpha_{XE,j}^{\frac{1}{\rho_j}} XE_{t,j}^{\frac{\rho_j - 1}{\rho_j}} \right)^{\frac{\rho_j}{\rho_j - 1}},\ \ j \in (agr, eng, ind, sev, aqu, sp_1, sp_3, sp)$$

Total supply:

$$X^S_{t,j} = \left(\alpha_{XD,j}^{\frac{1}{\rho_j}} XD_{t,j}^{\frac{\rho_j - 1}{\rho_j}} + \alpha_{XM,j}^{\frac{1}{\rho_j}} XM_{t,j}^{\frac{\rho_j - 1}{\rho_j}} \right)^{\frac{\rho_j}{\rho_j - 1}},\ \ j \in (agr, eng, ind, sev, aqu, sp_1, sp_3, sp)$$

where $XD_{t,j}$ is domestic production delivered for domestic demands.

2.1.6.6 The equilibrium

Real commodities:

$$X^D_{t,agr} = X^S_{t,agr} \ \Rightarrow p_{t,agr}$$

$$X^D_{t,eng} = X^S_{t,eng} \ \Rightarrow p_{t,eng}$$

$$X^D_{t,ind} = X^S_{t,ind} \ \Rightarrow p_{t,ind}$$

$$X^D_{t,sev} = X^S_{t,sev} \ \Rightarrow p_{t,sev}$$

$$X^D_{t,i,rf,har} = X^S_{t,i,rf,har} \Rightarrow p_{t,i,rf}\ ,\ i \in (1 \ldots sp_1)$$

$$X^D_{t,i,pf,pro} = X^S_{t,i,pf,pro} \Rightarrow p_{t,i,pf,pro}\ ,\ i \in (1 \ldots sp_3)$$

Composite commodity:

$$X^D_{t,aqu} = X^S_{t,aqu} \ \Rightarrow p_{t,aqu}$$

2.1.6.7 Factor markets

Total labour demands: $\sum_j L_{t,j}$, $j \in (agr, eng, ind, sev, mt, pro)$

Total labour supply: $\overline{L}_t$

In equilibrium: $\overline{L}_t = \sum_j L_{t,j}$

Wage rate: $\overline{w_t}$, exogenous

Capital demand by producer: $K_{t,j}$, $j \in (agr, eng, ind, sev, mt, pro)$

Capital supply by producer: $K_{t-1,j}$, $j \in (agr, eng, ind, sev, mt, pro)$

In equilibrium: $K_{t,j} =_{t-1,j}$, $j \in (agr, eng, ind, sev, mt, pro)$

Rental rate: r_t , endogenous to equilibrate the demand and supply.

2.1.6.8 Price system

Since the leading prices are $p_{t,agr}$, $p_{t,eng}$, $p_{t,ind}$, $p_{t,sev}$, $p_{t,sp_1,rf}$, $p_{t,sp_3,pf,pro}$, $p_{t,sp_1,rf,maq}$, $p_{t,sp_3,pf,maq}$, r_t , which to adjusted to equilibrate supply and demand constraints, and given the exogenous $\overline{w_t}$, all other prices can be derived from them by dual function.

For agriculture, energy, industry or service producer

$$p_{t,eis} = \left(\alpha_{eng}^{\rho_{eis}} p_{t,eng}^{(1-\rho_{eis})} + \alpha_{ind}^{\rho_{eis}} p_{t,ind}^{(1-\rho_{eis})} + \alpha_{sev}^{\rho_{eis}} p_{t,sev}^{(1-\rho_{eis})}\right)^{\frac{1}{1-\rho_{eis}}}$$

$$p_{t,aa} = \left(\alpha_{agr}^{\rho_{aa}} p_{t,agr}^{(1-\rho_{aa})} + \alpha_{aqu}^{\rho_{aa}} p_{t,aqu}^{(1-\rho_{aa})}\right)^{\frac{1}{1-\rho_{aa}}}$$

$$p_{t,io} = \left(p_{t,aa}^{(1-\rho_{io})}\alpha_{aa} + p_{t,eis}^{(1-\rho_{io})}\alpha_{eis}\right)^{\frac{1}{1-\rho_{io}}}$$

For harvest producer *j* ’s activity, $j \in (1...mt)$

$$p_{t,j} = \begin{pmatrix} \alpha_{aqu}^{\rho_{har}} p_{t,aqu}^{(1-\rho_{har})} + \alpha_{fbs}^{\rho_{har}} p_{t,fbs}^{(1-\rho_{har})} + \alpha_{agr}^{\rho_{har}} p_{t,agr}^{(1-\rho_{har})} \\ + \alpha_{eng}^{\rho_{har}} p_{t,eng}^{(1-\rho_{har})} + \alpha_{ind}^{\rho_{har}} p_{t,ind}^{(1-\rho_{har})} + \alpha_{sev}^{\rho_{har}} p_{t,sev}^{(1-\rho_{har})} + \alpha_{l}^{\rho_{har}} w_{t}^{(1-\rho_{har})} + \alpha_{k}^{\rho_{har}} r_{t}^{(1-\rho_{har})} \end{pmatrix}^{\frac{1}{1-\rho_{har}}}$$

3 *Calibrations and solutions*

For each region the model is calibrated based on a regional SAM data, following standard procedure. The SAM data is in value. The first task of calibration is to find a set of prices, which can balance the SAM values. Once the prices are found out, volumes can be obtained. The model needs to assume or separately estimate a number of substitution elasticity. With the information above, all parameters necessary to various functions can be calibrated.

Following two main computational procedures (Appendices 1*E* and 1*F*), the model currently is solved for base case. Any scenarios can be incorporated into the model subject to policy concerns.

Since the model features with recursive dynamics, it is convenient to solve it simultaneously. However, we are aware that forward-looking behaviour may not be the best approach to dynamics. Backward-looking investment may also be modelled in future.

3.1 Social Accounting Matrix

CGE modelling normally starts from the construction of a Social Accounting Matrix (SAM), which not only takes input-output table as its core to describe product flows but also extends beyond the table to record income flows and transfers between agents. A typical SAM may include production, commodities, factors, institutions, capital, and foreign accounts. These accounts are organised in a matrix table to provide a bird's eye view of an entire system of national or regional accounts. Each account in the table comprises a row and a column. The row lists the receipts or credits and a column the expenditures or debts.

The column of production account records intermediate requirements of commodities and primary requirements of factors for production, while the row gives the output of production activities. In commodities account, the column shows that commodities are supplied from domestic production and foreign (import) and the row tells how the commodities are sold to production, consumption, investment and foreign (export). Factors account is a bit implicit. Its column indicates that factor incomes need be re-distributed to agents and foreign as expenditures while the row records the receipts of factor incomes from value added of production. Institutions account can be split into three sub-accounts, namely households, firms and government. It is straightforward to see that the column and row of households account shows income expenditures such as household consumption, transfers to other households and to government, savings, and transfers to foreign and income sources such as factor incomes, and transfers from other households, government and foreign. Similarity is with government account where the column indicates income expenditures such as government consumption, transfers to households, government savings, and transfers to foreign and income sources including various taxes. Firms account normally is omitted. The column of capital account is investment, while the row lists savings from households, government and foreign. The last account is foreign flow account, which is also called current account. Its column consists of export, incomes from foreign and foreign savings, and the row includes import and incomes to foreign.

It is essential for a policy-oriented CGE model to be based on the data of real economy. The SAM provides CGE modelling with convenient and systematic presentation of the real data. Normally CGE modelling uses the SAM at a typical year to calibrate initial values of variables and various shares of equations in the model, following a standard method. Prior to calibration, elasticities of equations need be assigned values, which may be obtained from econometric estimation or best-guess, or directly from literature. After calibration the model should be able to run a base case that reproduces the SAM used. Afterwards, policy scenarios can be simulated and the results will be compared to the base case to draw insights.

SAM is originally designed to present national macroeconomy, but it can be as well applied to describe regional economies with microeconomic details. The SAMs used in the project are specially defined at the NUTS 3 level where a detailed fishery sector (fleet, species and commodities) and its link with the rest of the regional (and national/rest of the world) economy is considered. The SAMs of the five case studies have been set up in the same format (see figure below). They are presented in detail in Failler (2004).

From each case study SAM, the contribution of fisheries, aquaculture and related activities to

			Expenditures									
			Activities		Commodities		Households		Factors		Final Demand except domestic consump by residents	**Total Income**
			Fishing	Non Fishing	Fish	Non Fish	Fishers	Non Fishers	Labour	Capital		
Incomes	Activities	Fishing			Supply Table							
		Non Fishing										
	Commodities	Fish	Use Table				hh consump expenditure				FD-hh exp	
		Non Fish										
	Households	Fishers							lab income residents	mixed income residents + cap income local firms		
		Non Fishers										
	Factors	Labour	remuneration									
		Capital	net oper surplus									
		Goverment	net production taxes		net taxes on products		direct taxes					
		Imports			Imports							
		Saving/Invest					hh savings				gvt savings + foreign invest	
		Total Expenditure										

the local economy can be identified as follows:

- Production activities by fleet-segments and types of aquaculture production units;
- Supply of aqua-food products by species;
- Intermediate consumption of goods & services provided by other local activities or imported into the region;
- Employment by skill and capital usages by type in fishing industry;
- Wages, return rates, and thus value added;
- Domestic and foreign consumption of aqua-food products by species;
- Income redistributions between economic agents;
- Various taxes, tariffs and subsidies.

To construct a SAM with special treatment of fishing sector at regional level (NUTS3), a few of important issues demand particular attentions. First, a regional input-output table need be developed. This may be partly based on national input-output table but will also require considerable amount of information on the local economy. Second, the fishing sector need be specified with great details to incorporate information on species, fleet, fishermen and fish markets. This would require substantial fisheries economic and financial data, fisheries household data, and biological data. Finally, since the method is to be applied to five different regions in the project, it would be an efficient way to do the job if a standard procedure of construction of regional SAMs can be established. However, as the regional economies vary considerably, it is difficult to apply a unique, standard procedure to all of them. Instead, we have to differentiate the SAMs to certain extent subject to local specialities and information availability. For instance, the Salerno SAM takes into account 19 species and 5 fleets while the Bornholm one is limited to 6 species and 4 fleets. The economic structure also varies: the Pontevedra SAM defines two level of government while the others only have national government.

3.2 General equilibrium analysis on fisheries

Fisheries economics has traditionally focused in the interaction between economic harvest of marine fish and biological growth of the fish stock. It seeks the optimal goals for both producer and consumer of fish and explores policy implications in moving towards the goals. Normally, fisheries economic analysis stays at microeconomic level, so it is also called fisheries bioeconomics. On contrary, macroeconomic analysis on fisheries is rare. The existing research in this direction was dominated by input-output analysis where fisheries sectors are specified and linked with the system of all national economic sectors to capture interrelations between fisheries and other economic sectors. The input-output analysis of fisheries has two main drawbacks, one is that it normally sets up exogenous demands to drive fisheries production and another there is no price mechanism.

General equilibrium analysis has obvious advantages over input-output analysis in that it not only considers all sectors in a national economic framework but also generates production and consumption on basis of agents' behaviour and includes a powerful mechanism of price adjustment, which gives much room for policy analysis. However, so far only an unpublished research has reported a general equilibrium approach on fisheries for the Oregon region (Houston et al, 1997). This study built up a general equilibrium model including five fishing sectors, five fish-processing sectors and 24 other sectors, three types of factor income, household income categories, two government expenditures, imports and exports, and investment. Three scenarios were designed and conducted with the Oregon CGE model. The first scenario assumed a 20% reduction in groundfish catch because the fishery has become less productive and/or more restrictive due to stock decline. The second scenario considers a case of $6 million buyback of 16 trawl boats. Finally, the third scenario assumes a removal of 16 trawl boats. Under the three policy scenarios, Houston *et al*. (1997) estimate changes in numbers of jobs (i.e. employment impacts of reduced groundfish harvests). The results show a bigger change (effect) on scenario 1.

The problem with the Oregon model is that it is not tied with marine biological process, impact of fishing activity on marine system is not assessed and the feedback from marine system to economic system is exogenously given. In other words, there is no endogenous relationship defined between fishing productivity and fish stock changes. The present research within the PECHDEV project is intended to fill in the gap by linking our CGE model with a marine biological model, which is also constructed within the project.

3.3 Biological model

3.3.1 Data

Catch data were extracted from the International Council for the Exploration of the Sea (ICES) database using the FAO software FishStatPlus for most of the fish populations of interest. In the case of high-sea fishing for Pontevedra, catch data came from NAFO working groups and from the "Sea Around Us" project database (http://www.seaaroundus.org). Stock assessments data were extracted from the ICES working groups and Advisory Committee on Fisheries Management (ACFM) reports. They all can be downloaded on the ICES web site for the most recent years. For some fish populations of the Salerno region, stock assessments were available by the G5 operational unit (Spedicato *et al.*, 2003). Parameters of natural mortality required in the case of exponential production models were either extracted from the International Commission for the Scientific Exploration of the Mediterranean Sea (ICSEM) for the Salerno region, either from literature.

3.3.2 Generalized production models

Stock assessments in Europe are mainly conducted through single-species analyses based on cohort analysis principles developed by Gulland (1965), and leaned on some of Beverton and Holt (1957) hypotheses. This classic population dynamics framework allowed the development of powerful tools for the study of fish population dynamics such as Virtual population Analysis (VPA). The VPA method consists in studying abundance through catch data in order to produce estimates of fishing mortality and numbers at age that explain the stock history and its recent trends. The Extended Survivor Analysis (XSA; Shepherd, 1999) is nowadays the method widely used for management purpose and particularly by the ICES Working Groups to assess fish stocks. XSA outputs are notably used for long-term projections of yield per recruit analysis. These projections allow to visualize the future yield per recruit that should be obtained according to multipliers of the current fishing mortality, based on the assumption that the exploitation pattern remains constant. Yield per recruit analysis is thus used as a diagnostic to assess how the recruitment of a given stock is "used". We aimed to use this available information to specify surplus production models for the selected stocks.

In this perspective, generalized production models (Pella and Tomlinson, 1969; equation 1) were used as biological production functions for all the stocks for which yield-per-recruit functions were available or could be estimated:

$$\frac{dB}{dt} = rB\left(1 - \left(\frac{B}{K}\right)^{m-1}\right) - FB \quad (1)$$

where B is the biomass, t is the time, r is the growth rate, K stands for carrying capacity, m is the skewness (or shape) parameter and F is the fishing mortality.

For the regions of Finistère, Cornwall, Pontevedra and Bornholm, yield-per-recruit tables and mean recruitment values were generally available for the stocks assessed by ICES working groups. In the Salerno region, yield-per-recruit diagnostics have been conducted through Thompson and Bell (1934) models for some of the stocks. In each case, a generalized production model (Pella and Tomlinson, 1969) was fitted to the long-term projection yield data simulated by assuming a constant mean recruitment. The parameters of the model were estimated by least squared methods. In order to account for possible decreasing trends in recruitment for some stocks, a linear relationship between fishing mortality and recruitment was assumed following:

$$\begin{cases} R = \overline{R} \quad if\ F < F_{\lim} \\ R = \dfrac{\overline{R}}{F_{\lim} - F_{crash}} \times R - \dfrac{\overline{R} \times F_{crash}}{F_{\lim} - F_{crash}} \quad if\ F > F_{\lim} \end{cases} \quad (2)$$

where R is recruitment, Rbar is the mean recruitment, F is fishing mortality, F_{lim} stands for the fishing mortality from which a decrease in recruitment is observed and F_{crash} the fishing mortality at which the recruitment becomes null (Lassen and Sparholt, 2000). F_{lim} and F_{crash} are available for some stocks from ICES working group reports.

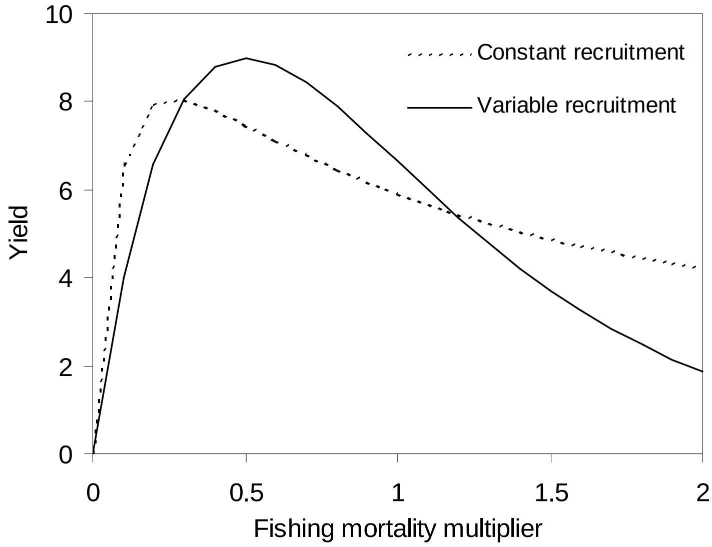

Figure 2: Surplus production models estimated for the Celtic cod for a constant recruitment (dash line) or a recruitment linearly decreasing from F_{lim} (solid line).

3.3.3 Exponential production models

For most of the species that are not submitted to quota management, very few information is available on their population dynamics. In this context, an empirical approach based on time-series of catch data and exponential production models (Fox, 1970; equation 3) was used:

$$\frac{dB}{dt} = rB\left(1 - \frac{\ln(B)}{\ln(K)}\right) - FB \qquad (3)$$

where B is the biomass, r is the intrinsic growth rate, K is the carrying capacity and F is the fishing mortality.

This methodology first requires to re-express the commonly used parameters r and K of the exponential model in function of the maximum sustainable yield (MSY) and the fishing mortality at MSY (F_{MSY}) (equation 4).

$$\begin{cases} r = F_{MSY} \times \ln\left(\dfrac{MSY \times \exp(1)}{F_{MSY}}\right) \\ K = \dfrac{MSY \times \exp(1)}{F_{MSY}} \end{cases} \qquad (4)$$

where r is the intrinsic growth rate, K is the carrying capacity, MSY is the maximum sustainable yield and F_{MSY} is the fishing mortality at MSY.

The approach assumes that MSY can be estimated following expert judgment or from the time-series of catch data. This suggests that the stock has been exploited for a long time and that the MSY has been reached in the past. F_{MSY} is assumed to be equal to the natural mortality of the stock (Gulland, 1971). Current fishing mortality is then estimated by solving the biomass at equilibrium in the current situation (equation 5):

$$B_{curr} = K \times \exp\left(\frac{-F_{curr} \times \ln(K)}{r}\right) \qquad (5)$$

From the catch time-series, different situations can occur:

- if a clear maximum of catch is observed in the time series, then the MSY corresponds to catches averaged on 10 years around the period where the maximum is observed. Because two solutions can exist for equation (5), the current fishing mortality at equilibrium is either set to its high or low value according to the current status of the stock i.e., over or underexploited respectively
- if the maximum of catch is observed in the last years, then the stock is supposed to be at MSY. The MSY is set to an average of the last ten years of catch
- if no clear maximum is visible from the time-series, the MSY is conventionally set equal to the average of the last ten years of catch, as precautionary approach.

Ecological aspects[3]

Ecological aspects can be separated into two categories, 1) trophic interactions and 2) ecological constraints from abiotic forcing. The marine species (and/or groups of species) selected for the Salerno case are shown below, with interspecific links (predator-prey) and depth distribution. Broken arrows represent predator-prey relationships among species that strongly depend on the age class of predator and prey. By contrast, unbroken arrows represent interspecific relationships that do not depend primarily on age classes, for instance, with bluefin tunas that prey on anchovies and pilchards of all ages (see figure 6). The specification of major feeding relationships in the Salerno ecosystem is a first step towards the development of a multispecific approach to integrate predation interactions for the Salerno stocks. The mathematical formalism adopted here would allow to simulate ecological scenarios and quantify the potential economic impacts of changes in the trophic structure of the Salerno marine food webs.

However, interspecific trophic relationships are not taken into account at this stage for three main reasons. First, the biological model is not age-structured and therefore age-dependent predator-prey relations cannot be described. Second, the primary inter-species relationship between bluefin tuna and anchovies and pilchards cannot be included since the three species are located in different areas, and therefore in different ecosystems. In particular, anchovies and pilchards are caught by “coastal fleets” (purse-seiners) in “coastal waters” (falling in GFCM sub-geographical area 10), where tuna catches come from other coastal areas. As explained in the species selection, tuna vessels mainly fish in the Adriatic (sub-geographical areas 17 and 18), Ionian (19), in the waters south of Sicily (15 and 16) and in the Ligurian sea (9). As a consequence, interspecific relationships can be left out as the stocks do not refer to the same area. Third and finally there is almost no information i.e. stomach contents or stable isotope data, available on predator-prey relationships in the ecosystem food webs studied in the Salerno case (figure 6). Stock assessment data in the Mediterranean are generally very poor, dictating the use of simpler biomass dynamic models.

[3] The ecology is presented here for the Salerno case study due to time constraints.

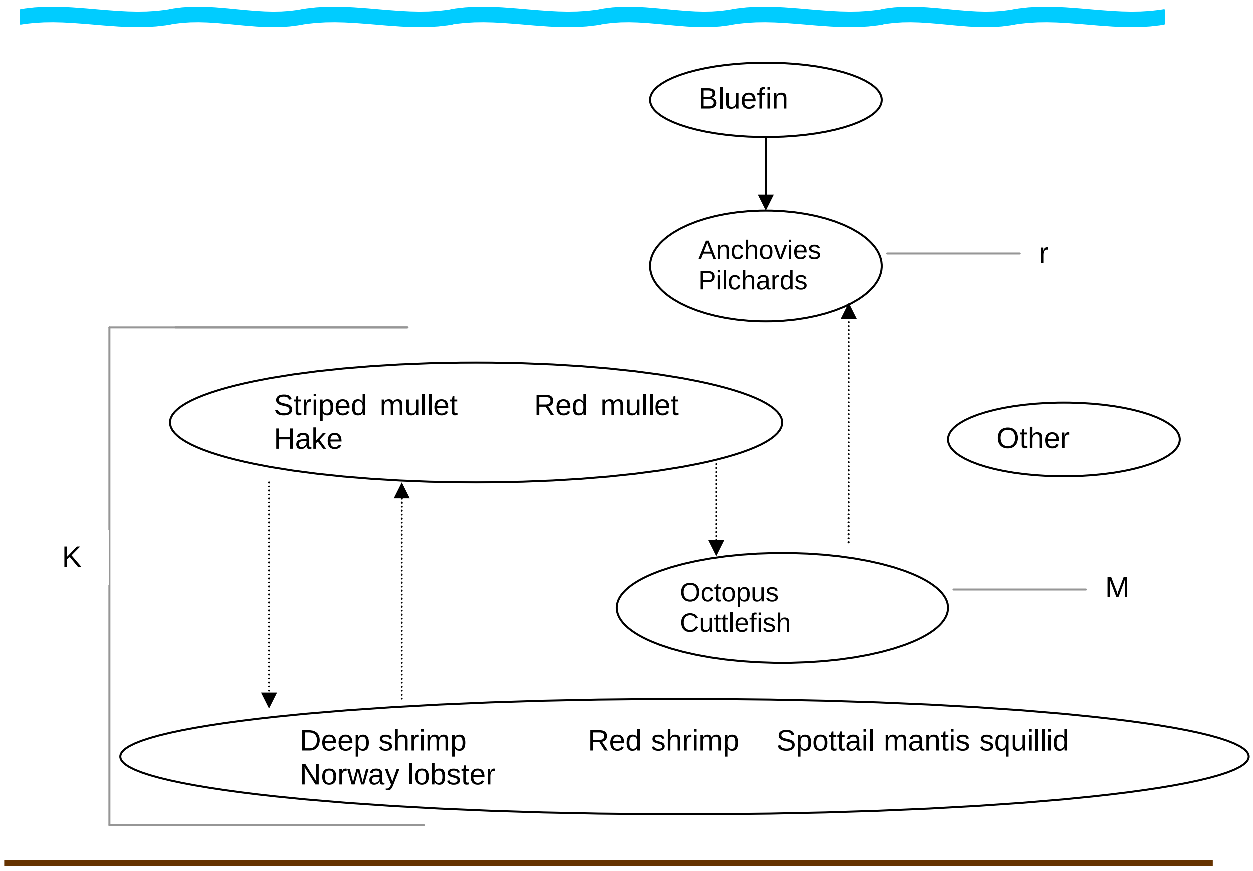

Figure 3: Interspecific relationships (predator-prey) and depth distribution of the selected species for the Salerno case.

Thus, the only ecological considerations in the model relate to the impacts of abiotic factors on the biological production parameters K (carrying capacity), r (instantaneous growth rate) and M (natural mortality). For the Salerno province, three main ecological factors have been chosen: water quality, phytoplankton and zooplankton abundance and temperature, that all relate to ecosystem health. The aim of the analysis is to specify underlining assumptions regarding the impact of ecosystem change on the species production.

Among the 13 main fisheries species, the two red shrimps species (*Aristaemorpha foliacea* and *Aristeus antennatus*) are excluded from the ecological box because the fishing grounds of the Salerno trawler fleet is a shoal located very far from the coast (the “Bocca Grande” bank) outside the “Salerno province ecosystem” described in the Ecological framework. Similarly for bluefin tuna (*Thunnus thynnus*), which are caught in waters outside the Salerno province ecosystem. Nonetheless, economic simulations can focus on the fleet reactivity parameter (β) to the bluefin tuna stock that covers the whole Mediterranean sea and is also exploited by other fleet segments (Italian, European and non EU fleets).

The abiotic ecological factors and their links with the biological and economic modules developed for the Salerno case study are detailed below.

3.4 Water quality

The water quality, as highlighted in the ecosystem description of the Salerno province, is measured through a synthesis index, the CAM (Classificazione delle Acque Marine, CAM –

Classification of Marine Waters), that is built starting from values of salinity, transparency, chlorophyll, ammonia, phosphates, nitrates, nitrites and silicates. On the basis of this complex index, the coastal waters can be subdivided into three quality classes, in which quality refers to the eutrophication status of the coastal systems and to the potential relevance of hygiene-sanitary hazards. The three classes are:

- *High quality*: unpolluted waters. These in general are open sea waters, or waters that do not receive inflow from the coastline or other perturbations of antropic origin. These waters are typically characterised by low phytoplankton biomass and scarce nutrients and organic and inorganic particulates;
- *Intermediate quality*: waters with a variable eutrophication level, that are nevertheless ecologically intact. Their eutrophication level depends on terrigenous contributions or on other enrichment sources (in trophic terms) deriving from marine coastal waters. These waters are characterised by a conspicuous phytoplankton biomass. They are also capable of producing efficiently new biomass. Enrichment in this case does not lead to an unbalancing of the ecological status of the system, which is still capable of metabolising excess nutrients.
- *Low quality*: eutrophicated waters, showing environmental alterations also of human origin. In this case, waters are subjected to not negligible eutrophication phenomena. Additionally, they are not capable of producing efficiently new biomass. This kind of situation characterises many river mouth areas, in which great quantities of nutrients and particulates carried by the river are released into the sea and reduce transparency. This impairs the use of nutrients by phytoplankton and reduces system productivity and, therefore, carrying capacity.

The value of the CAM index has been available since 2001 from three monitoring stations of the Salerno province coast[4]. It is likely to assume that a change in the water quality can affect the overall ecosystem health. It is also likely that the ecosystem health is directly linked with the concept of carrying capacity (K) defined as “the point of balance between reproduction potential and environmental resistance, that is the maximum population of a species that a specific ecosystem can support indefinitely without deterioration of the character and quality of the resource” (Scialabba, 1998). Following the partition of the CAM index values into three classes as defined above, three different case studies were considered to simulate variations in the carrying capacity parameter: increase, decrease and constancy of the parameter value relative to the reference situation. These variations were assumed to be of the same magnitude for all the species, except for red shrimps and bluefin tuna as stated before, because water quality was supposed to be globally and homogeneously affected by pollution.

3.5 Phytoplankton and zooplankton abundance

The other ecological factors that will be considered is the abundance of phytoplankton and zooplankton. In aquatic ecosystems, phytoplankton has a crucial role as it represents the first level of the food web. It is made up of autotrophic organisms able to use sun energy, through photosynthesis process, in order to transform inorganic components into organic ones used by animal organisms for their vital processes. Phytoplankton includes a number of species that are different in terms of size, morphology, physiology and ecology. The most important are diatoms and dinoflagellates. Diatoms are unicellular or colonial algae. They can be

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[4] Ministero dell’Ambiente e della Tutela del Territorio, Servizio per la Difesa del mare, Programma di Monitoraggio per il Controllo dell’Ambiente Marino-Costiero, Triennio 2001-2003. World Wide Web electronic publication (www.sidimar.ipzs.it).

pelagic or benthic. Dinoflagellates are microalgae and have a motor appendix, called flagello. On the other hand, zooplankton is the animal component of the plankton and represents the second level of the marine food chain. Zooplankton organisms feed of phytoplankton. The zooplankton is also characterised by a high number of species. The most important ones are copepods and cladocerans. Copepods are a subclass of crustaceans most represented in the plankton. They are very abundant and diversified in pelagic environments where they can colonise both surface and bottom waters. Cladocerans are microscopical crustaceans: their size is no more than a few millimetres. A few species live in sea or brackish waters. Cladocerans prefer to live in not very deep waters, close to the shore and rich with vegetation.

Values of abundance for phytoplankton (diatoms, dinoflagellates and other phytoplankton – cell/lt.) and zooplankton (cladocerans and copepods - individuals/mc) are available since 2001 (Ministero dell'Ambiente e della Tutela del Territorio, IT, Servizio per la Difesa del mare, 2001-2003). Plankton organisms are fundamental in the diet of anchovies and sardines. They feed both on phytoplankton - dinoflagellates and diatoms- and zooplankton - cladocerans and copepods - (Froese and Pauly, 2004). It is likely, then, to assume that variations in abundance of these food chain components will affect growth of their direct predators (Cury *et al*., 2000). Such a bottom-up effect can be simulated through the level of growth rate of these stocks i.e., by simulating variations in the *r* parameter of biological production functions. Modifications of this parameter were carried out for the two stocks of small pelagics harvested by Salerno fishing fleets: anchovies (*Engraulis encrasicolus*) and pilchard (*Sardina pilchardus*).

3.6 Natural mortality

Stock assessments are generally conducted by assuming constant natural mortality rates at each age, although multispecific approaches have been developed in order to relate such rates to predators abundance (e.g., Magnusson, 1999). Mortality rates can also be linked to environmental factors that are generally considered to affect fish pre-recruitment stages (Cushing, 1982). Within the ecological module of PECHDEV, we assume that environmental effects can have impacts on the natural mortality of cephalopods, because water temperature is an essential factor driving the lifespan of these species (Wood and O'Dor, 2000). In order to simulate such environmental effects on natural mortality, octopus (*Octopus vulgaris*) and cuttlefish (*Sepia officinalis*) were selected in the Salerno case study. Empirical production functions in the project were estimated by assuming that fishing mortality at maximum sustainable yield (MSY) can be set equal to the rate of natural mortality (Garcia *et al*., 1989). Varying the natural mortality for these two species then changes the values of their growth rate (r) and carrying capacity (K). In the reference situations, natural mortality of cephalopods was set to 3 (Royer *et al*., 2002). Two alternative functions with M set at 2.5 and 3.5 were estimated.

4 Empirical results

4.1 Economic results

The CGE model for regional fisheries economy can be used to simulate the economic activity and conduct policy analysis. Normally, economic analysis of fishery management policies requires the evaluation of economic impacts of changes in economic conditions on fisheries. Two different scenarios for policy analysis and fisheries management are considered: (i) management by economic incentives and (ii) management by capture control (that can assimilate to quota for species under this regime). Under the first scenario, we add a tax on some fish products to divert fish production and consumption away from endangered species. The second scenario simulates a controlled production of fisheries to protect some species from extinction.

In the previous work of the project, a CGE model was not successfully constructed and its applications to the five European regions were also failed. However, recently we have re-developed a new CGE model for fisheries, which is presented in details in previous sections. The model is a basic model, which need be modified for economic analysis on each region. Because of time constraint, at time being we are unable to apply the model to all five regions. Instead, we use it for a case study of the Salerno economy for the reason that the region's economic data are readily available. An illustrative table of the Salerno SAM is given in Appendix 1*G*. The complete SAM used for the modelling is much detailed, which we are unable to present with this paper.

The Salerno SAM table shows that the region's fisheries include fishing and processing sectors only and no aquaculture. Fishery-related business service and fish marketing service are embodied in normal industrial or service sectors, not given separately. The fishing sector has five metiers, namely bottom trawler, purse seiner, small-scale fisheries, multi-purpose fishery, and tuna fishery. They harvest 13 species such as blue fin tuna, anchovies, common cuttlefish, common octopus, red mullet, deepwater rose shrimp, European pilchard, European hake, giant red shrimp and blue and red shrimp, striped mullet, Spottail mantis squillid, Norway lobster, and other species. The fish processing sector only processes blue fin tuna, anchovies, and some other species. The original agriculture sectors, energy sectors, industrial sectors, and service sectors are aggregated into agriculture, energy, industrial and service sector. The Salerno SAM data also distinguishes between fishery and non-fishery households.

At outset we run a base case to reproduce the economy in reference year and project it for next eight years. We assume a simple situation where the economy grows gradually due to continuous investment (see Figure 4). We focus on the fisheries. During the period, except for Bluefin tuna, the production of all other species will decline (see Figures 5 and 6). Although bluefin tuna production will grow, the species' biomass stock will grow as well (see Figure 7). Like bluefin tuna, the biomass stock of Norway lobster and European pilchard will also grow. The other 10 species' biomass stocks all show declining trend in the end of the period (see Figures 8 and 9). Particularly, both common cuttlefish and striped mullet will extinct (see Figure 9).

Scenario 1 studies the case when a 10% consumption tax is added on the prices of common cuttlefish and striped mullet. The results show that this instrument is not really effective. The biomass stocks change a little but not enough for protection.

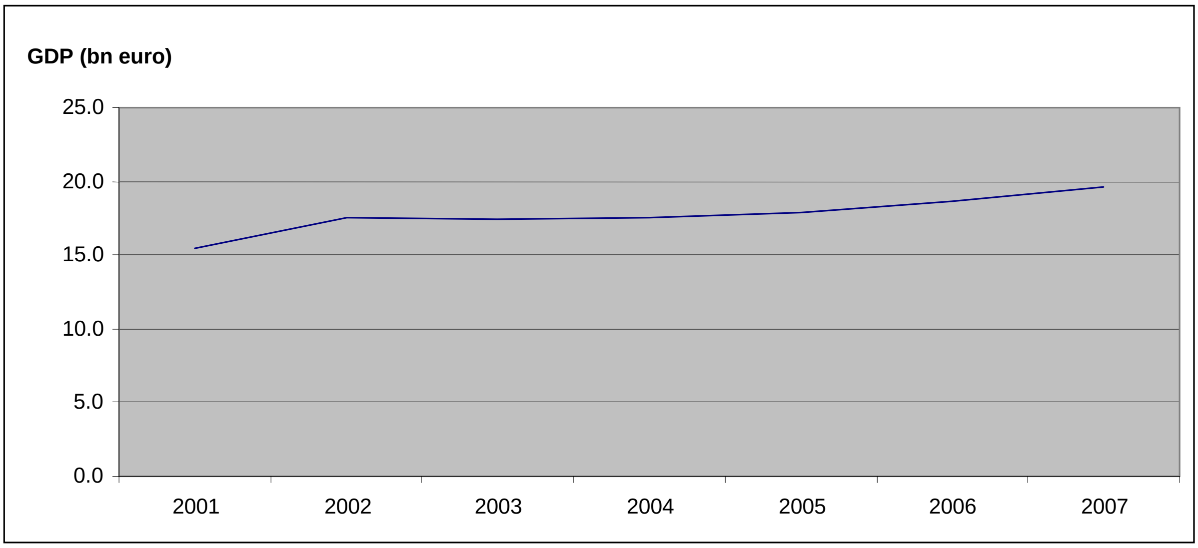

Figure 4: GDP growth of the Salerno economy

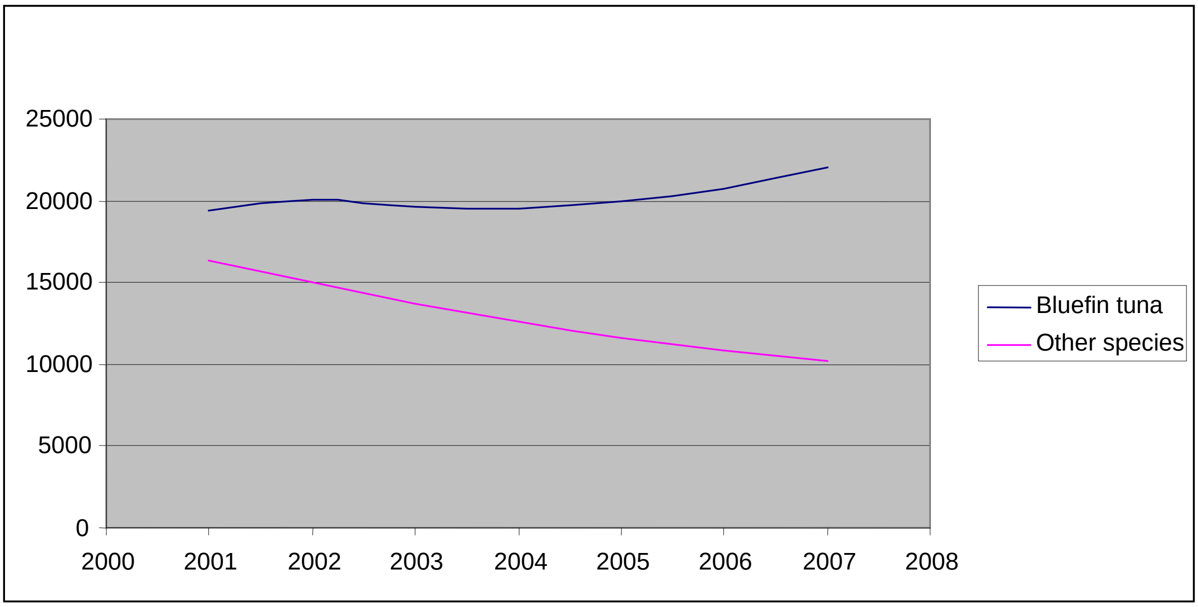

Figure 5: Fish Production (1)

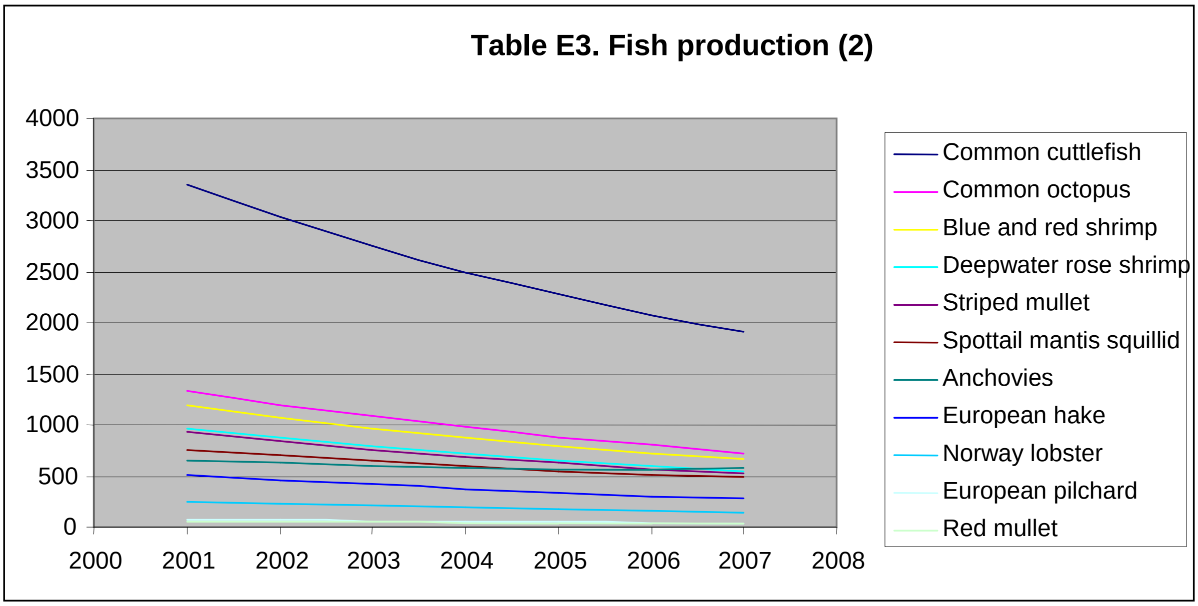

Figure 6: Fish Production (2)

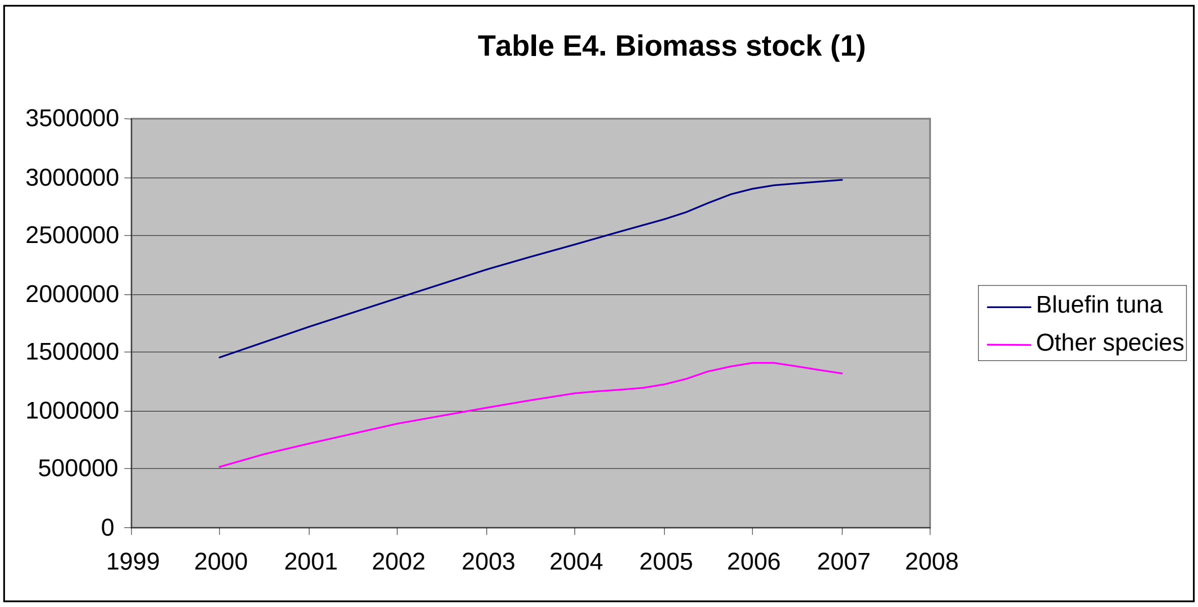

Figure 7: Biomass stock (1)

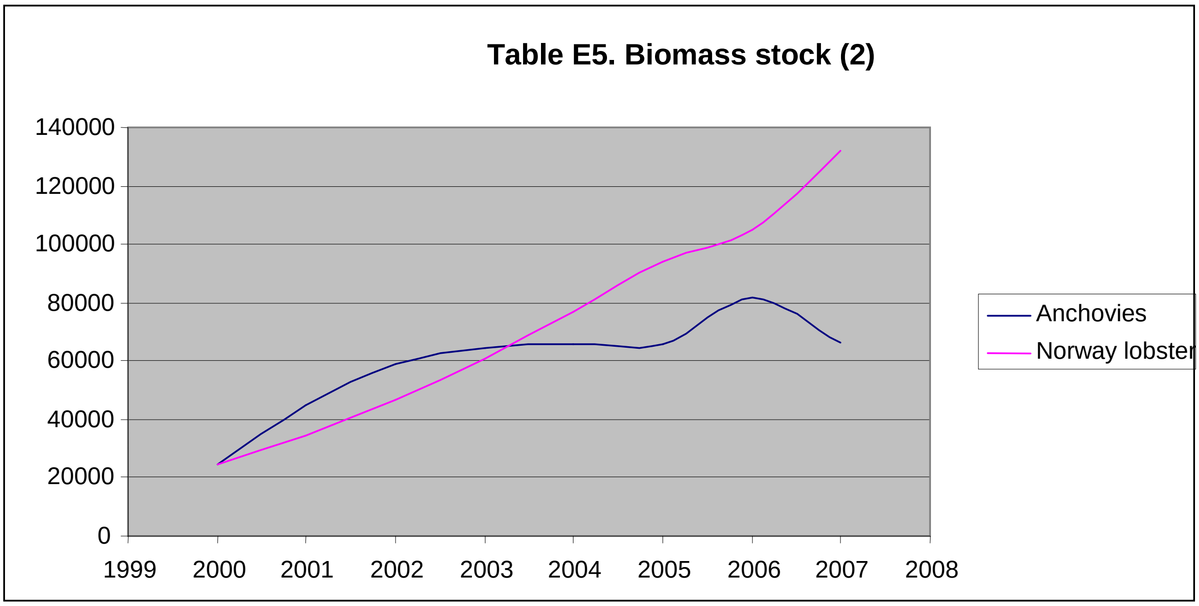

Figure 8: Biomass stock (2)

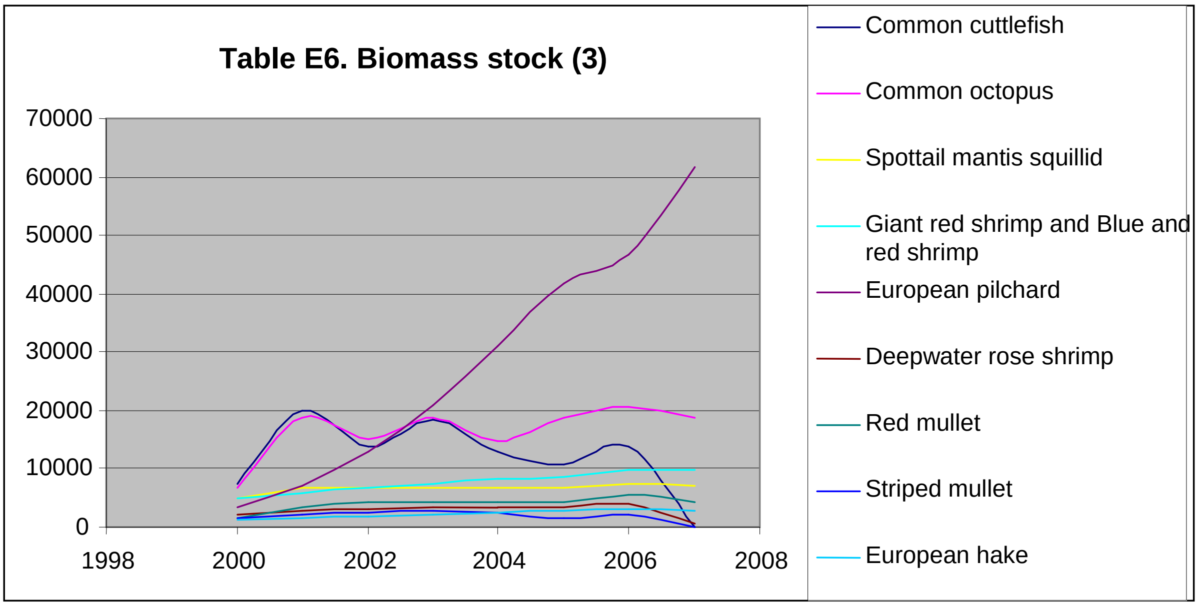

Figure 9: Biomass stock (3)

The case study with the Salerno verifies that the general equilibrium model with focus on fisheries can provide a great room to explore policy implications relevant to fisheries. Using it, we are able to simulate dynamic changes of fishing effort and biomass stock, competition between wild fishing and aquaculture, resource movement between sectors, industrial transition, employment and income distribution in fisheries society, demand change in response to price change, and etc.

The model however cannot be designed uniformly for each region. Subject to each region's economic specialities, the model has to be tailor-made to certain extent. For each region, the classifications with respect to consumer, producer, and commodity have to be redefined. Data availability is another serious problem with the application the fishery CGE model. Lacking of time-series or cross-sectional data, we have to empirically assume rather than estimate most of substitution elasticity. Biomass growth parameters are also different across different growth functions. The simplest case is the linear growth function. Other growth functions such as logistic, exponential, and generalized production functions require more parameters to be specified.

4.2 Biological results

4.2.1 Finistère

Most of the stocks exploited by Finistère fishing vessels are assessed by ICES working groups. Therefore, information on their state and dynamics was available except for *Cancer pagurus* in the Channel not assessed and *Nephrops Norvegicus* in the Celtic Sea for which few information is currently available (ICES, 2003c). The current state of *Cancer pagurus* stock was given according to expert judgment (D. Latrouite, *pers. com.*). Celtic cod displays a decreasing trend in recruitment with time (ICES, 2004), therefore its biological production function was estimated by accounting for a possible recruitment overexploitation following equation (2). Table 1 gives the population parameters for the stocks selected for Finistère and stock areas, natural mortality coefficients and unit values are given in appendix 2.

Table 1: Population parameters for the stocks selected in Finistère. Alpha represents the part of the stock targeted by Finistère fishing fleets and Bcurr is the current total biomass of the stock (in '000 euros).

Scientific name	r	K	m	Alpha	Bcurr
Cancer pagurus	1.92	358953.5	1.00	0.137	132051.6
Coryphaenoides rupestris	-0.02	660611.7	0.09	0.307	135939.4
Gadus morhua	-0.12	394854.1	0.41	0.715	17302.6
Lepidorhombus whiffiagonis	-0.10	1859500.1	0.55	0.219	204330.3
Leucoraja naevus	-0.37	134544.1	0.62	0.503	40361.0
Lophius piscatorius & budegassa	-0.06	5683694.2	0.43	0.361	393529.4
Melanogrammus aeglefinus	-0.31	90227.9	0.45	0.356	24668.3
Merlangius merlangus	-0.09	389644.2	0.15	0.244	63132.3
Merluccius merluccius	-0.15	3538713.5	0.53	0.055	470243.3
Nephrops norvegicus (MA L)	3.69	216311.0	1.00	0.129	79576.4
Nephrops norvegicus (MA M)	3.70	230368.9	1.00	0.513	84748.0
Nephrops norvegicus (MA N)	-0.12	1090885.3	0.50	0.513	109356.4
Others	6.62	15583912.2	1.00	0.031	5733000.9
Pollachius virens	-0.06	4887832.7	0.32	0.020	443526.7

4.2.2 Bornholm

In the case-study of Bornholm, only 5 fish stocks were selected that represent the majority of fish production (See Species and stocks selection, this paper). Actually, two different cod stocks (eastern and western Baltic) are harvested but they were combined in one stock as a first approach. In a second step, they should be separated because their current state and economic importance for Bornholm are very different. Generalized production models were used for *Gadus morhua* and *Sprattus sprattus* whereas the 4 other stocks were assigned exponential models (Table 2) Few information was available for *Pandaleus borealis* and a unique stock occupying West and East Greenland was considered and assumed at the MSY situation, as a precautionary approach (Appendix 3). Regarding plaice (*Pleuronectes platessa*), the state of the stock was considered underexploited because the stock is hardly threatened as it is only exploited by a small limited summer fishery (H. Lassen*, pers. com*).

Table 2: Population parameters for the stocks selected in Bornholm. Alpha represents the part of the stock targeted by Bornholm fishing fleets and Bcurr is the current total biomass of the stock (in '000 euros).

Scientific name	r	K	m	Alpha	Bcurr
Gadus morhua	-0.20	9919213.9	0.51	0.053	610983.4
Others	6.04	3619195.4	1.00	0.004	1331427.6
Pandaleus borealis	31.37	474410.3	1.00	0.021	174525.8
Pleuronectes platessa	1.21	186226.6	1.00	0.163	153696.1
Salmo salar	2.40	163324.6	1.00	0.098	19504.7
Sprattus sprattus	-0.16	304552.9	0.10	0.034	141055.8

4.2.3 Cornwall

Regarding the Cornwall region, generalized production models were fitted for 4 of the 12 stocks selected (Table 3). An important part of the production comes from fish populations not assessed by ICES working groups and for which very few information is available (A. Forest, *pers. com*). This is notably true for crustaceans (*Cancer pagurus*) and shellfish (*Pectinidae*) with a lack of good knowledge on their dynamics and the current state of the stocks (Appendix 4). The stock of edible crab was assumed at MSY in the current situation following expert judgment (D. Latrouite, *pers. com*). In the same way, the stock of pollack was considered at MSY although some fishermen of Brittany begin to observe declining catch (Y. Morizur, *pers. com*). For the remaining stocks, their current state was also considered at MSY, in the perspective of a precautionary approach (see discussion below).

Table 3: Population parameters for the stocks selected in Cornwall. Alpha represents the part of the stock targeted by Cornwall fishing fleets and Bcurr is the current total biomass of the stock (in '000 euros).

Scientific name	r	K	m	Alpha	Bcurr
Cancer pagurus	1.92	356013	1.00	0.181	130969.9
Gadus morhua	-0.12	577144	0.41	0.109	25290.6
Lepidorhombus whiffiagonis	-0.10	2121253	0.55	0.082	233093.0
Lophius piscatorius & budegassa	-0.06	5700416	0.43	0.074	394687.2
Merluccius merluccius	-0.15	5277809	0.53	0.010	701343.7
Microstomus kitt	2.44	199446	1.00	0.221	73372.2
Others	6.14	4690330	1.00	0.017	1725475.9
Pectinidae	2.40	161553	1.00	0.452	59432.0
Pollachius pollachius	2.37	138823	1.00	0.254	51070.3
Psetta maxima	2.32	111708	1.00	0.173	41095.0
Scomber scombrus	3.13	6123873	1.00	0.003	1720851.3
Solea solea	1.46	2209449	1.00	0.056	714357.6

4.2.4 Pontevedra

Although twenty fish stocks were first selected for the Pontevedra case-study, including the 'others' group, only eighteen biological production functions were finally estimated. This was due to the lack of information and data for the stocks caught by high-sea fishing fleets. Fish harvested by these fleets are mainly composed of three important species: common squids (*Loligo spp.*), hake (*Merluccius hubbsi*) and Greenland halibut (*Reinhardtius* *hippoglossoides*). The high difficulty linked to the identification of their fishing grounds and the amounts of fish landed in Vigo, combined with the already empirical approach to specify surplus production models, prevented to estimate any function from the information available. It was then preferred to aggregate the three species in a 'high-sea stock' considered at MSY instead of specifying biological parameters based on unobjective criteria and certainly wrong assumptions. All shellfish stocks were assumed to be underexploited following local expert judgments. Therefore, the current yield was considered to be equal to 90% of the MSY (Appendix 2). This should allow to visualize a possible increase in catch following a raise in the capital or labour of shellfishing activities. Only 5 of the 18 stocks were estimated following the approach based on generalized production models, whereas the 13 remaining stocks were assigned exponential models.

Table 4: Population parameters for the stocks selected in Pontevedra. Alpha represents the part of the stock targeted by Pontevedra fishing fleets and Bcurr is the current total biomass of the stock (in '000 euros).

Scientific name	r	K	m	Alpha	Bcurr
Cerastoderma edule	2.28	90659.6	1.00	0.311	49341.0
Conger conger	2.40	159353.6	1.00	0.361	58622.9
High Sea stocks	4.73	7119456.1	1.00	0.306	2619101.5
Lepidorhombus spp. (CF)	-0.12	466943.6	0.31	1.020	145847.3
Lepidorhombus spp. (DSF)	-0.10	5424093.7	0.55	0.385	596024.1
Loligo vulgaris	25.94	49358.0	1.00	0.097	18157.8
Lophius spp. (CF)	2.08	1043615.3	1.00	0.163	254881.4
Lophius spp. (DSF)	-0.06	17961958.1	0.43	0.058	1243655.8
Merluccius merluccius	-0.15	11000036.9	0.53	0.112	1461744.1
Merluccius merluccius	-0.13	2314999.9	0.46	0.254	325143.5
Nephrops Norvegicus	4.39	2251696.0	1.00	0.033	828352.7
Others	6.88	29324879.4	1.00	0.027	10788020.2
Pollicipes cornucopiae	2.31	102348.9	1.00	1.000	55702.8
Rajidae	2.15	1720129.6	1.00	0.179	632800.3
Ruditapes decussatus	2.62	478603.0	1.00	0.227	260479.7
Venerupis Pullastra	2.08	32456.5	1.00	1.010	17664.5
Venus verrucosa	2.59	431086.7	1.00	1.217	234618.9
Xiphias gladius	4.32	1799238.5	1.00	0.097	901266.7

4.3 Ecological results

4.3.1 Water quality

Biological production functions were estimated for Salerno by considering a 33% increase and a 33% decrease for the K parameter relative to the reference situation. The alternative functions estimated concern the following species: *Merluccius merluccius*, *Mullus barbatus*, *Mullus surmuletus*, *Nephrops norvegicus*, *Octopus vulgaris*, *Parapaeneus longirostris*, *Sepia officinalis*, *Squilla mantis*, *Thunnus thynnus* and the 'Others' group. Variations in the K parameter modify the order of magnitude of the production functions according to the yield axis but do not affect the shape of the curves (Figure 10). Therefore, it increases (or decreases) each stock yield for a given fishing effort when the K parameter is increased (or decreased). Improvement of water quality quantified through the CAM index is thus directly transferred to all stocks selected as an increase in the potential of catch. On the other hand, deterioration in water quality due to pollution is traduced by a decrease of the equilibrium curve along the yield axis. Tables of alternative production functions are given in appendix 1.

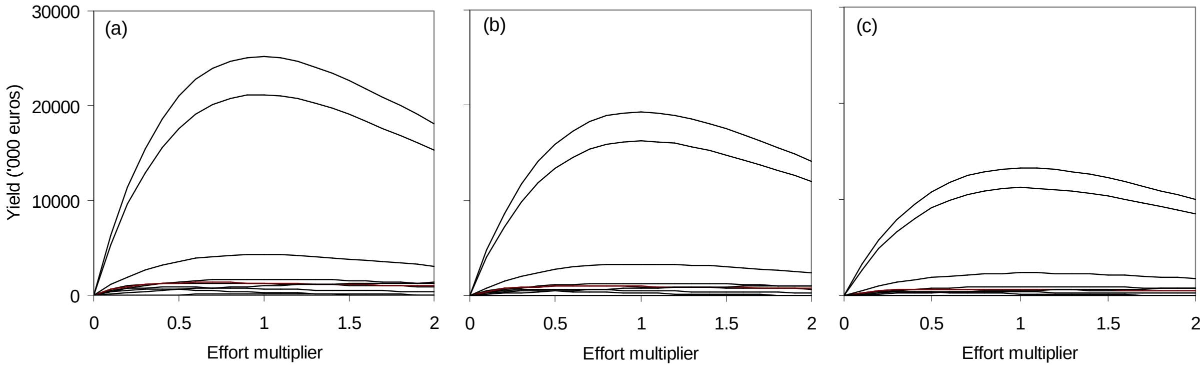

Figure 10: Local biological production functions estimated when simulating (a) a 33% increase of the K parameter (b) Reference situation (c) a 33% decrease of the K parameter.

4.3.2 Phytoplankton and zooplankton abundance

Biological production functions were estimated considering possible impacts of phytoplankton and zooplankton abundance on small pelagic stocks. A 10% increase (or decrease) of the r parameter for the stocks of *Engraulis encrasicolus* and *Sardina pilchardus* led to an increase (or decrease) of the production functions (figure 5). Such a variation implies a direct bottom-up control of phytoplankton and zooplankton abundance towards small pelagics catches. Table of alternative parameters are given in appendix 2.

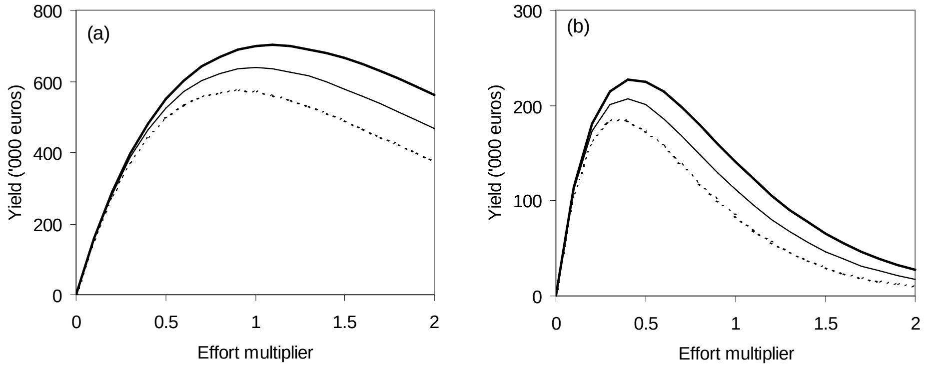

Figure 11: Local biological production functions estimated when simulating a 10% increase (dash line) or 10% decrease (thick solid line) in the growth rate parameter of (a) *Engraulis encrasicolus* (b) *Sardina pilchardus*.

4.3.3 Natural mortality

Biological production functions were estimated when considering alternative values of natural mortality (M) (figure 6). Increasing M decreases the value of K and increases the value of r. This leads for both species to similar results with a production curve moving towards the right along the x-axis. The MSY remains constant for the 3 production functions but it is reached for a higher fishing mortality i.e. a higher fishing pressure when M is increased. For low fishing efforts, catches are lower in the case of a higher natural mortality whereas they become higher for high fishing efforts.

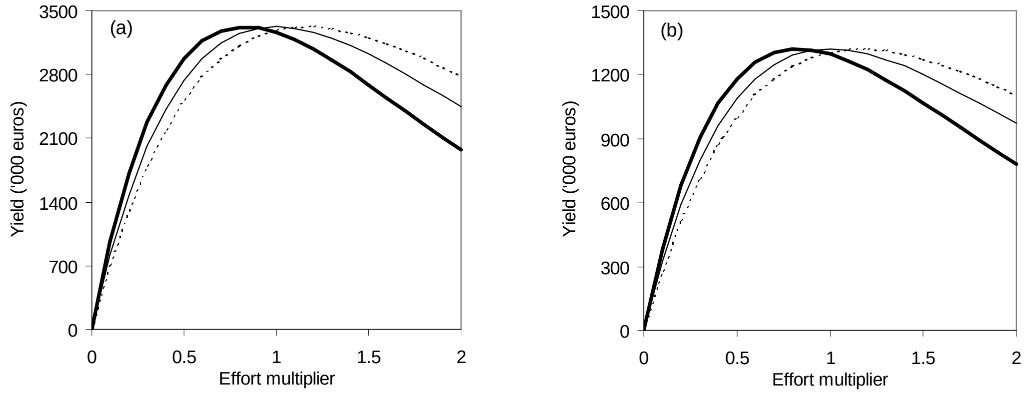

Figure 12: Local biological production functions estimated when setting the natural mortality to 2.5 (thick solid line); 3 (solid line) and 3.5 (dash line) in the case studies of (a) common cuttlefish (*Sepia officinalis*) (b) common octopus (*Octopus vulgaris*).

5 Discussion

5.1 Economic considerations

The results for Bornholm show a decrease in value of total production, as well as in value of fisheries production, when we increase the tax on fisheries. When a decrease in production from the fishery (by 10%) is simulated, the results show an increase in value of total production as well as in value of fisheries production. However, when a decrease in production from the fishery by 15% is simulated, an increase in value of total production and decrease in value of fisheries production is found.

Are also reported the changes in Labour and Capital parameters under the above 4 scenarios for each case study. For Bornholm, a decrease in labour and increase in capital occur when simulation scenarios 1 and 2 are run (ie. increase tax on fisheries). However, when a decrease in the fishery production is simulated, the results show an increase in Labour parameter and decrease in Capital parameter.

The key component of the PECHDEV project is the link between dynamics of exploited fish populations and the economy of a region dependent on fishing. This required careful study on what kinds of mathematical models would be appropriate for such a holistic approach, and how to integrate biological production functions into the computable general equilibrium model. It also addressed the problem of model estimation, based on very heterogeneous and sometimes absent data sets. The approach retained is thus based on ad-hoc methods constrained both by the structure of the economic module and by the availability in biological data.

5.2 Biological and ecological considerations

5.2.1 Scope

Within the PECHDEV project, each case-study required to specify which fishing activities would be included in the SAM so as to segment the fish production sector into various homogeneous components. These fishing segments were defined according to different criteria but were mainly based on fleet typologies already existing. For the 5 regions, the segments are mostly related to the vessels capacity (power and/or length) and the types of gears, adapted to certain fish species. The fishing capacity is closely linked to the distance vessels can go fishing. This appeared relevant in terms of costs spent because most of them are due to gas expenditures. Because the analysis is made on a global scale, a reasonable number of fleets was considered so as to find a balance between the relevance of the fishing fleets, the data availability and a high complexity. This pragmatic approach seems appropriate at the regional level regarding the data quality for many of the other sectors of activity and according to the general objectives of the project. The multispecific aspect of most of the fishing segments considered raises the challenging questions of technical interactions and the different problems to assess and predict effort reallocation. Such issues should be addressed with the CGEM and appear essential in the current context of overexploitation of several stocks and the necessity to evaluate the possible impacts of quota reductions.

5.2.2 Data quality and availability

The need to define models for all the stocks selected (including the ‘others’ group) emphasized the lack of knowledge available for many commercial populations of fish, crustaceans and shellfish in Europe. Considering the absence of stock assessment data, production functions were estimated following an empirical method for a high number of fish stocks (see below). The approach required to have a time-series of catch data available by FAO and to make strong assumptions on the stock dynamics. However, in some cases, even no information on the geographic distribution and current state of the stock were available despite their economic importance at the regional and national levels. For the province of Salerno, the low quality of stock assessment in the Mediterranean region (Lleonart and Maynou, 2003) combined with a poor quality of catch data made difficult the estimation of the production functions. The lack of data was also particularly underlined in the case of high sea fishing for the Pontevedra province because the nature of the landings from this fishery remain mostly unknown. This might be linked to the absence of applied legislation in high sea areas. Regarding the lack of information on the current state for many fish stocks, they were considered at the MSY situation, as a precautionary approach. This assumption allows to traduce any increase in fishing effort by a decrease in catch.

5.2.3 Surplus production models

In the context of the PECHDEV project, biological production functions had to be estimated for the 63 stocks selected in the 5 regions. The choice of biomass dynamic models was made for three reasons: i) simplicity of the models ii) homogeneity according to data availability iii) link with the economic module. Estimation of surplus production model parameters is not straightforward and it is generally based on time-series of catch-effort data. Different methods including pseudo-equilibrium, regression and observation error/time-series fitting exist in fisheries science, although these latter are generally considered to be the best ones (Hilborn and Walters, 1992). Gathering catch-effort data (when they exist) for the stocks of interest and conducting assessments through classic methods would have however been a difficult, indeed impossible, task to do within the duration of the project. Also, this would have been far beyond the scope of the project that is mainly centred on socio-economic issues and policy management. Moreover, estimating parameters of biomass dynamic models for the most exploited stocks of European waters is almost impossible because they have been harvested for a long time and catch-effort data are generally only available late after the onset of the fisheries. Therefore, current data when they are available do not show historical variation in stock size and fishing pressure, necessary to estimate the parameters of the model with any reliability.

5.2.4 Estimation methods

The methodology developed within the project aimed to use the maximum of information available on the dynamics of the stocks selected, following the existence or not of stock assessment data. The first approach used age-structured models through long-tem yield-per-recruit analysis to estimate biomass dynamic models. This method is pretty original in the sense that it combines analytical and surplus production models whereas these two types of approach are rarely compared. Surplus production models describe the dynamics of the stock in terms of biomass, rather than numbers at age. Therefore, the current values of fishing mortality estimated by VPA for the exploited age-classes can not be used as mortalities to estimate the parameters of the biomass dynamic models. The current fishing mortality was thus quantified from yield-per-recruit and biomass-per-recruit values available in the ICES reports. The use of long-term projections based on yield-per-recruit and constant recruitment is however debatable since the right part of the curve corresponding to high fishing efforts is rather hypothetical (rarely observed) and does not account for any trend in the recruitment of the stock. The assumption of constant recruitment to establish the production function can thus lead to overoptimistic predictions with stocks displaying a strong resistance to fishing in terms of catch stability for the high fishing efforts. This led to values of the shape parameter (m) inferior to 1, and hence negative values for the growth rate parameter (r), because the two parameters are correlated. A simple model assuming a linear relationship between fishing mortality and recruitment was developed to account for a possible declining trend in recruitment (equation 2). This model used F_{crash} and F_{lim} as thresholds although these indicators are estimated for the exploited part of the population only. Despite these drawbacks, the objective of this model was to show that taking into account such trends can strongly modify the parameters estimated and lead to more pessimistic functions.

5.2.5 A local production function

From the biomass dynamic model estimated for the whole stock, we deduced a local production function through the alpha parameter, because regional fishing activities only represent a part of the total catch on the stock. This parameter allows to study a local stock impacted by the regional fleets and it is assumed constant in time. Such an assumption seems reasonable for all the species submitted to quota management because the Total Allowable Catch (TAC) is distributed between the member countries and between fishermen organizations according to fixed quotas. For the other species, considering alpha constant appeared as a pragmatic approach and it was globally verified for the majority of the species despite some minor variations in time. The alpha parameter should therefore be estimated as an average for a few years in order to avoid any variability linked to a particular year. This was not always possible in the 5 case-studies because only one year of local landings was available. In the case of Pontevedra, values of the parameter alpha for 3 stocks are higher than 1. This implies that the landings (in tonnage) from the local fishing fleets are higher than the total landings for the whole stock. This can be linked to different causes: bad estimates for the total catches, local landings and lag between landings from a given year and catches at equilibrium. Again, using several years of landings in Pontevedra to estimate alpha should lead to more accurate values of alpha.

5.2.6 Linking biology and economy

The link between biology and economy within the CGEM is made through the CPUE table, which both affects and depends on the change of biomass stock. It seems important to recall that estimating the SAM required hard work and strong assumptions to move from data generally available at a higher spatial scale (e.g. national) to the regional SAM. Notably, in the case-studies of Pontevedra and Bornholm, landings in value were extrapolated from input/output matrix and therefore did not match well with landings in tonnage given by official statistics. This led to stocks unit values (i.e., prices) that could be quite different from real prices observed in landing harbours. These estimated prices were assumed at equilibrium and used to move from a biological production function in tonnage to a production in value. This was the only possible approach in order to be consistent in the economic and biological modules respectively. Another difficulty emerged from the time-lag that could exist between the year of availability of economic data and the years at which stock assessments are made. In the ideal case, both modules should be estimated at the same time to adjust current local landings to the current catch and state of the stock. Again, this was not possible for reasons of data availability but it should be kept in mind when discussing simulation results. We believe that such data problems might poorly affect the general patterns in the simulation results because the main issues addressed by CGEM deal with the global structure of the regional economy and the trends in variables of interest.

6 Conclusions

The contribution of natural marine resource production industries (fishery and aquaculture mainly) to regional development is estimated with a Social Accounting Matrix (SAM) and its dynamics are simulated and explored through a Computable General Equilibrium Model (CGEM). The SAM establishes linkages at two main levels: (1) the fishery level between fleet and fish stocks within their ecosystem (2) between fisheries and aquaculture activities and the rest of the regional economy (at Nuts 3 level). The key idea was to link the local economy of the fisheries sector to coastal marine ecosystems and see how much one can affect the other and vice versa. These aspects are often hidden due to a lack of information to describe 1-fisheries economic activities at local and sub-national level, giving a weak picture of coastal activities overall; 2-coastal ecosystems and fish stocks other than those with a significant landing value at ICES level. Unfortunately, the link has not been fully realise and required further work.

From the biological point of view, specifying biomass dynamic models from empirical methods appeared as the most pragmatic and appropriate approach to develop the biological module of the CGEM. Despite all the uncertainty and possible criticisms of the present method, one strongly believes that the level of accuracy of the biological models is close to the quality of economic data of the regional SAM, and consistent with the objectives of the project. Thus, simulations carried out with the CGEM should not imply large variations in catch because the production factors of fishing activities generally vary within a limited range of values. Moreover, output results of CGEM are analysed by looking at the trends in the changes occurring within the economic sectors of the region rather than the exact values estimated.

From the ecological point of view, the ecological approach within the PECHDEV project is closely coupled with the biological module through direct relationships assumed between ecological variables and the biological production functions. In the Salerno case, alternative functions were linked to ecological descriptors (water quality, plankton abundance and temperature) because, due to their availability, they give a tangible sense to any possible scenario. Such an approach was based on expert knowledge and required to clearly identify the main factors able to affect the dynamics of exploited fish populations. Assumed relations between ecological descriptors and parameter values remain however very empirical and mostly aim to emphasize that there might be a strong link at the ecosystem scale between ecosystem health and biological production. This calls for further investigations and refinements to well establish such relations. More particularly, it seems intuitive that these relationships may be non-linear and more easily observable for local stock units in the case of terrestrial pollution. Ecological simulations carried out with the Computable General Equilibrium Model (CGEM) considering alternative biological functions should take into account the current ecological state of the ecosystems, and be seen as exploratory runs to visualize the possible trends within the regional economy linked to such scenarios. This should eventually lead to a better understanding of the tight coupling that can exist between ecosystem health and fisheries-dependent economic activities.

7 Acknowledgments

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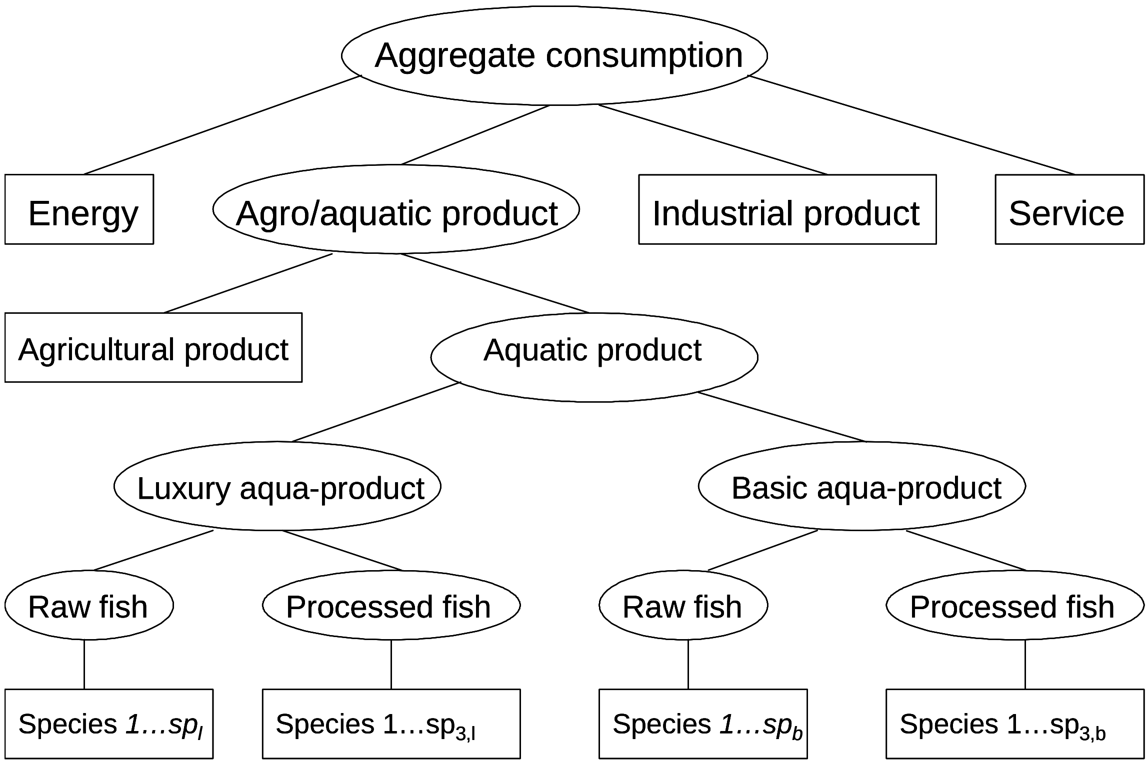
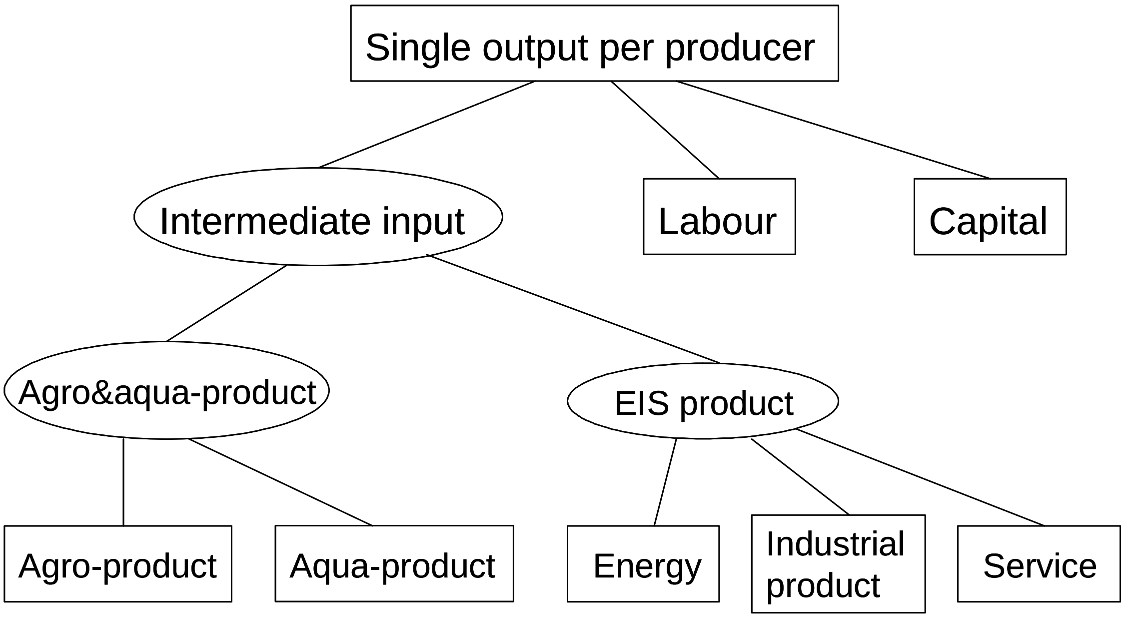
Appendix 1A: the nested consumption scheme

The nesting consumption scheme



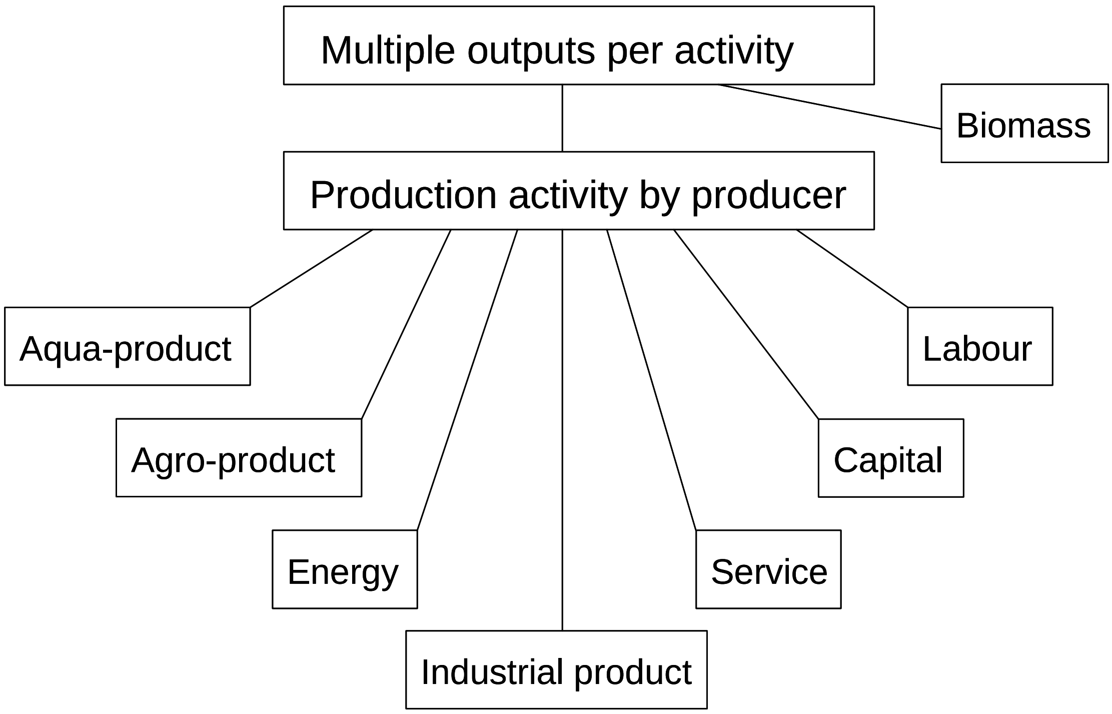
Appendix 1B: the nested production scheme for Agricultural, Energy, industrial and service producer

The nested production scheme for *Agricultural*, *Energy*, *Industrial*, or *Service* producer



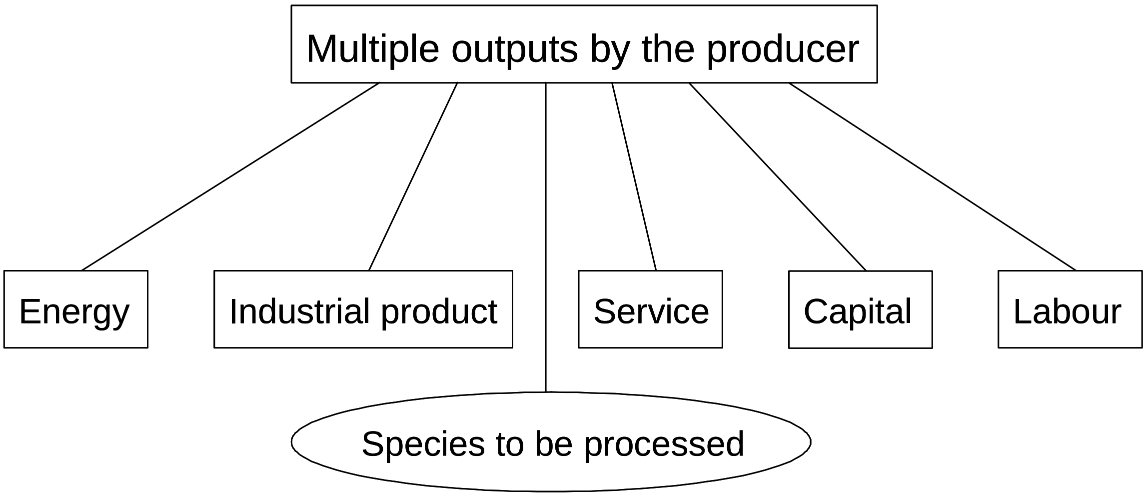
Appendix 1C: the nested production scheme for fshing producers

The nested production scheme for *Fishing* producers (the Metiers)

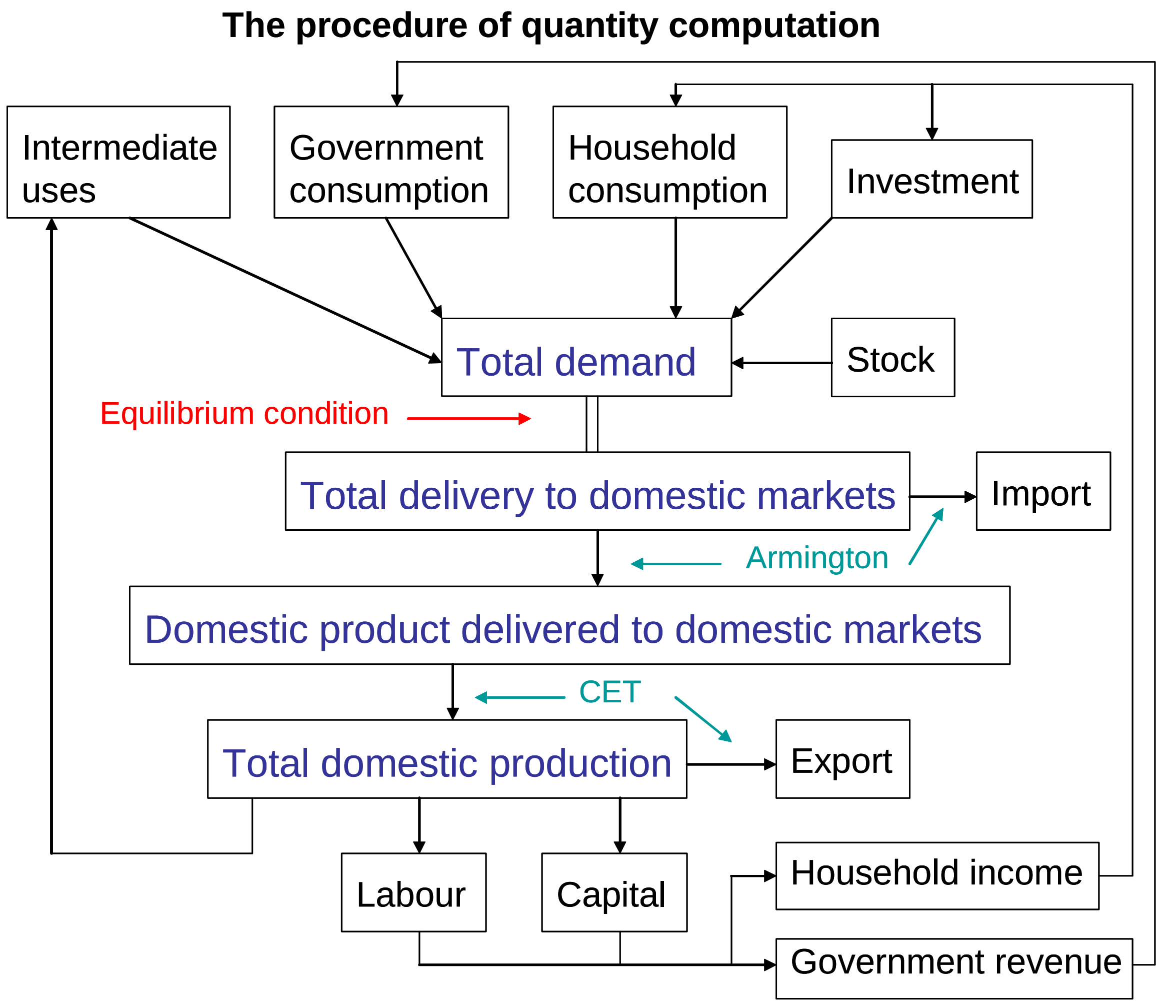


Appendix 1D: the nested production scheme for fishery processing producer

The nested production scheme for *Fishery processing* producer

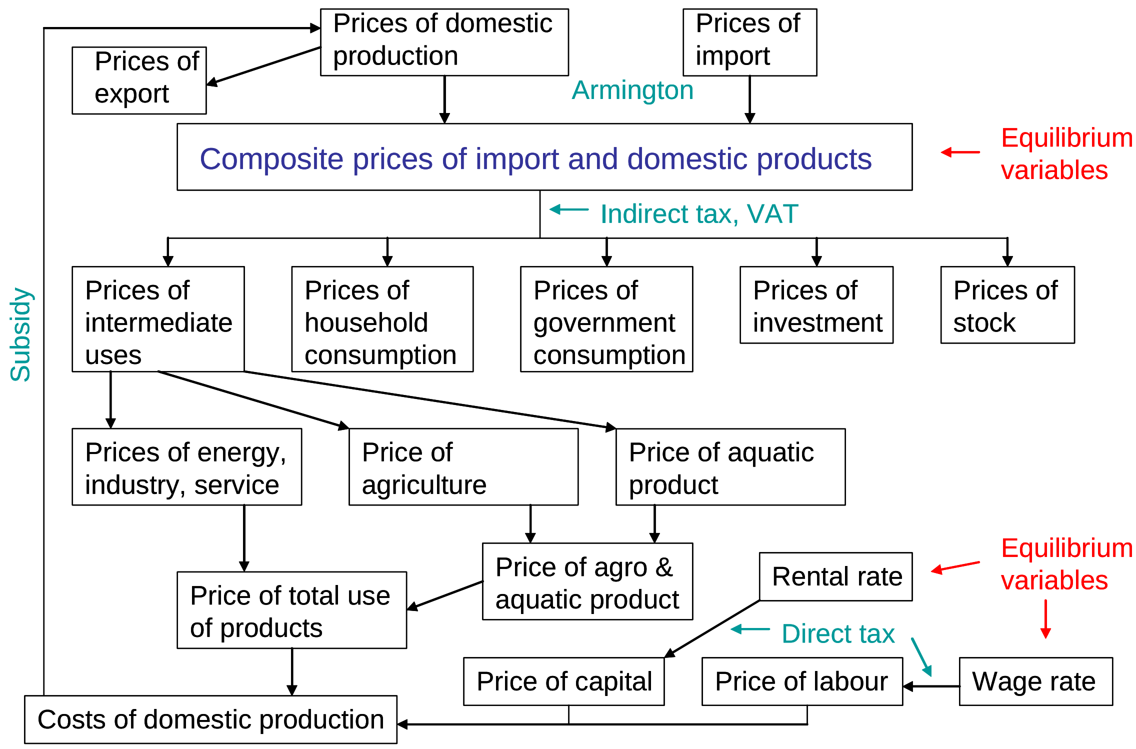


Appendix 1E: The procedure of quantity consomption



Appendix 1F: the procedure of price computation

The procedure of price computation



Appendix 1G: A typical SAM table for Salerno

The Social Accounting Matrix (SAM) for Salerno	Producers	Products	Labour	Capital	Non fisher household	Fisher household	Government	Taxes & subsidies	Foreign	Savings	*Total*
Producers		27816616									**27816616**
Products	12532885				7681849	30830	4388866		8500259	793700	**33928389**
Labour	6832203										**6832203**
Capital	7657829										**7657829**
Non fisher household			6815281	7641049			1315315				**15771645**
Fisher household			16922	16780			8250				**41952**
Government								6506131			**6506131**
Taxes & subsidies	793700	930721			4770589	11122					**6506131**
Foreign		5181052								3319207	**8500259**
Savings					3319207		793700				**4112907**
Total	**27816616**	**33928389**	**6832203**	**7657829**	**15771645**	**41952**	**6506131**	**6506131**	**8500259**	**4112907**	**117674062**

Appendix 2: Biological information

By ENSAR

Appendix 2.1. Stock area, current status, price (euros/kg), natural mortality (M) and sources of information for the fish stocks selected for Salerno.

Scientific name	Area	Status	Price	M	Source
Arist. foliacea-antennatus	Grund 5 area	MSY	22.72	-	Spedicato *et al.*, 1999
Engraulis encrasicolus	Sardinia	MSY	3.37	0.84	Mannini *et al.*, 2001
Merluccius merluccius	Grund 5 area	Overexploited	9.30	-	Spedicato *et al.*, 1999
Mullus barbatus	Grund 5 area	Close to MSY	10.86	-	Spedicato *et al.*, 1999
Mullus surmuletus	Sardinia	MSY	9.20	1.11	Spedicato *et al.*, 2003
Nephrops norvegicus	Sardinia	Overexploited	26.33	0.16	Spedicato *et al.*, 2003
Octopus vulgaris	Sardinia	MSY	6.77	3.00	Lanco, 1999
Others	Sardinia	MSY	6.42	0.40	Assumed
Parapaeneus longirostris	Grund 5 area	Close to MSY	11.98	-	Spedicato *et al.*, 1999
Sardina pilchardus	Sardinia	Overexploited	0.60	0.33	Pestana, 1989
Sepia officinalis	Sardinia	MSY	8.59	3.00	Lanco, 1999
Squilla mantis	Sardinia	Underexploited	4.75	1.41	Righini and Baino, 1996
Thunnus thynnus	East Atl. & Medit.	Overexploited	7.15	0.19	Ravier, 2003

Appendix 2.2 Stock area, current status, price (euros/kg), natural mortality (M) and sources of information for the fish stocks selected for Finistère.

Scientific name	Area	Status	Price	M	Source
Cancer pagurus	VIId-e	MSY	1.82	0.15	Assumed
Coryphaenoides rupestris	VI, VII, Vb	Underexploited	1.14	-	2004 - ACFM: 15
Gadus morhua	VII e-k	Overexploited	1.86	-	2004 - ACFM: 03
Lepidorhombus whiffiagonis	VIIb,c,e-k VIIIa,b,d	Overexploited	2.93	-	2004 - ACFM: 02
Leucoraja naevus	No stock defined	MSY	1.50	-	Assumed
Lophius spp.	VIIb-k VIIIa,b,d	Overexploited	3.62	-	2004 - ACFM: 02
Melanogrammus aeglefinus	VII b-k	MSY	1.03	-	2004 - ACFM: 03
Merlangius merlangus	VII e-k	MSY	1.18	-	2004 - ACFM: 03
Merluccius merluccius	IIIa, IV, VI, VII, VIIIa,b,d	Overexploited	2.59	-	2004 - ACFM: 02
Nephrops norvegicus (MA L)	VIIb,c,j,k (L)	MSY	5.99	0.3	Morizur, 1982
Nephrops norvegicus (MA M)	VIIf,g,h (M)	MSY	5.90	0.3	Morizur, 1982

Nephrops norvegicus (MAN)	VIIIa, VIIIb (N)	Overexploited	7.01	-	2003 - ACFM: 18
Others	VIIIa-d, VIIa-k	MSY	2.87	0.4	Assumed
Pollachius virens	IIIa, IV, VIa, b	Overexploited	0.85	-	2004 - ACFM: 07

Appendix 2.3. Stock area, current status, price (euros/kg), natural mortality (M) and sources of information for the fish stocks selected for Bornholm.

Scientific name	Area	Status	Price	M	Source
Gadus morhua	22-32	Overexploited	1.71	-	2002 - ACFM: 17
Others	22-32	MSY	1.43	0.4	Assumed
Pandaleus borealis	Greenland	MSY	3.95	2.4	Assumed
Pleuronectes platessa	22-29	Underexploited	1.75	0.1	WGNSSK, 2003
Salmo salar	22-31	Overexploited	3.37	0.2	Assumed
Sprattus sprattus	22-32	Underexploited	0.08	-	2003 - ACFM: 21

Appendix 2.4. Stock area, current status, price (euros/kg), natural mortality (M) and sources of information for the fish stocks selected for Cornwall.

Scientific name	Area	Status	Price	M	Source
Cancer pagurus	VIIe,f	MSY	1.93	0.15	Assumed
Gadus morhua	VII e-k	Overexploited	2.72	-	2004 - ACFM: 03
Lepidorhombus spp.	VIIb,c,e-k VIIIa,b,d	Overexploited	3.35	-	2004 - ACFM: 02
Lophius spp.	VIIb-k VIIIa,b,d	Overexploited	3.64	-	2004 - ACFM: 02
Merluccius merluccius	IIIa, IV, VI, VII, VIIIa,b,d	Overexploited	3.86	-	2004 - ACFM: 02
Microstomus kitt	VIIa,e,f,g,h,j	MSY	6.34	0.20	Assumed
Others	VIIe,f,g,h,j,k	MSY	2.52	0.40	Assumed
Pectinidae	VIIe,h	MSY	2.26	0.20	Assumed
Pollachius pollachius	VIIe,f,g,h	MSY	2.09	0.20	Assumed
Psetta maxima	VIIe,f,g,h,j	MSY	11.24	0.20	Assumed
Scomber scombrus	Western component	Overexploited	0.67	0.20	Assumed
Solea solea	VIIa,d,e,f,g,h,j,k	Overexploited	11.67	0.10	Assumed

Appendix 2.5. Stock area, current status, price (euros/kg), natural mortality (M) and sources of information for the fish stocks selected forPontevedra. CF = Coastal Fishing, DF = Deep-Sea Fishing.

Scientific name	Area	Status	Price	M	Source
Cerastoderma edule	VIIIc, XIa	Underexploited	2.17	0.20	Assumed
Conger conger	VIIIc, IXa	MSY	5.10	0.20	Assumed
High Sea stocks	Atlantic	MSY	5.81	0.30	Assumed
Lepidorhombus spp.	VIIb,c,e-k VIIIa,b,d	Overexploited	8.55	-	2003 - ACFM: 02

Scientific name	Area	Status	Price	M	Source
(CF)					
Lepidorhombus spp. (DF)	VIIIc, IXa	MSY	10.69	-	2004 - ACFM: 02
Loligo vulgaris	VIIb,c,g-k, VIII, IX	MSY	8.61	2.40	Royer *et al.*, 2002
Lophius spp. (CF)	VIIb-k VIIIa,b,d	MSY	11.45	-	2004 - ACFM: 02
Lophius spp. (DF)	VIIIc, IXa	Overexploited	14.54	0.15	WG South Angler
Merluccius merluccius	IIIa, IV, VI, VII, VIIIa,b,d	Overexploited	8.05	-	2004 - ACFM: 02
Merluccius merluccius	VIIIc, IXa	Overexploited	9.93	-	2003 - ACFM: 01
Nephrops Norvegicus	MA M & L	MSY	29.95	0.30	Morizur, 1982
Others	VIIIc, IXa	MSY	5.81	0.40	Assumed
Pollicipes cornucopiae	VII, VIII, IX	Underexploited	58.93	0.20	Assumed
Rajidae	VIIIc, IXa	MSY	4.85	0.15	Charuau and Biseau, 1989
Ruditapes decussatus	VIIIc, IXa	Underexploited	11.10	0.20	Assumed
Venerupis Pullastra	VIIIc, IXa	Underexploited	1.66	0.20	Assumed
Venus verrucosa	North Atlantic	Underexploited	8.68	0.20	Assumed
Xiphias gladius	VII, VIII, IX	Close to MSY	13.85	0.30	Kleiber and Yokawa, 2002

Appendix 3: Fishing fleets selection for the 5 regions

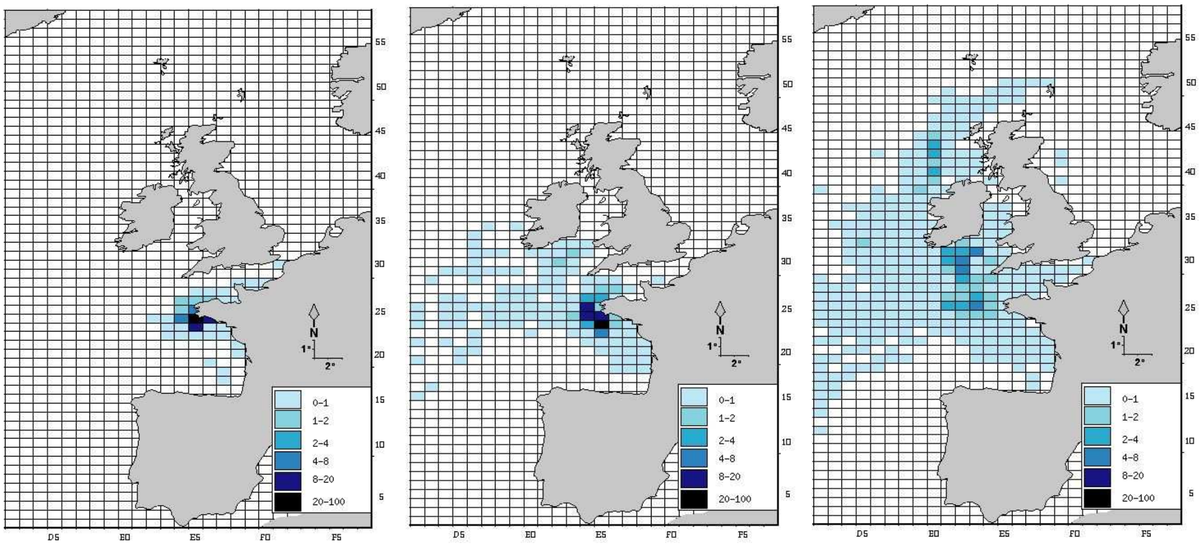
By ENSAR, IREPA, UCL, SDU, IHE-EHU

Introduction

Within the PECHDEV project, the interrelationships linking individual production sectors and factors as well as private, public and foreign institutions are defined through the Social Accounting Matrix (SAM). This matrix has been established for each of the 5 regions of interest and aims to segment the fish production sector in activities. However, the complexity of fisheries can make difficult any clear cut off between fishing fleets, especially in the case of multispecies multifleet fisheries, also called mixed fisheries. A fleet is often identified by the vessel and/or crew characteristics, the gear used, and sometimes the main species targeted. In reality, such descriptions are generally insufficient because vessels of a given fleet can exhibit different fishing practices in time (Pelletier and Ferraris, 2000). This corresponds to another level of fishing practices that exists (e.g. métiers; Laurec *et al*., 1991, fishing tactics, Laloë and Samba, 1991) but it will not be considered in the present analysis because the scale of study is very large. Various methods exist to make a typology of fishing fleets according to the objectives of the study. The PECHDEV project did not aim to develop any new methodology to select the fishing activities appropriate to the SAM. For pragmatic reasons, fleets segments already existing were chosen. The main objective was to segment the fish production in distinct and homogeneous fishing activities and for which economic data (e.g. fishing fleets costs) were available.

1. Finistère

In the SAM, the production fishing sector of Finistère was segmented into distinct fishing fleets that display homogeneous characteristics in terms of factors of production and species harvested. Current typologies are based on power or size of the boats because it relates to the distance the fishing vessels can go. In France, an alternative typology exists based on the notion of 'navigation title'. This title is a juridical status that defines the rights of fishing boats as well as fishermen according to French law. It notably establishes the time that fishing vessels can spend at sea (See report II) and it also defines the amount of social charges each fisherman has to pay, following the social security regime of seamen (Etablissement National des Invalides de la Marine). Based on these titles, the fishing fleet of Finistère was split into 3 fleets: small fishing, coastal fishing and off-shore fishing. The strong link between navigation title and distance of fishing makes relevant their use as a fishing vessels typology (Fig. 1). Actually, a high-sea fishing fleet also exists in Finistère. It is attached to the maritime district of Concarneau but it is located most of the time in West Africa and Indian Ocean. Moreover, fish harvested by these vessels (namely tuna) are landed in African and Seychelles harbours and can be processed there, before being exported to France or other countries in the world. For these reasons, the high-sea fishing fleet of Finistère was considered in the present analysis as an import sector.



(a) (b) (c)

Fig. 1. Geographical distribution of the landings in value (proportion of total landings) in Finistère by Finistère fishing vessels for each navigation title (a) Small fishing (b) Coastal fishing (c) Off-shore fishing.

A second criterion was added to segment the fishing activities according to their geographic location. It is generally admitted that Finistère exhibits very different types of fisheries between the northern part corresponding to the maritime districts of Morlaix, Brest and Camaret and the southern part composed by the districts of Douarnenez, Audierne, Concarneau and Le Guilvinec (Fig. 2). This distinction is globally linked to the difference in fishing grounds and hence in fish species harvested. Basically, the northern part of the Finistère is mainly characterized by small scale fisheries that mostly target crustaceans (*Cancer pagurus* and *Maja squinado*) and anglerfish (*Lophius spp*.). On the opposite, the southern part of Finistère is predominated by more industrial fisheries harvesting a higher number of species (e.g. gadidae) and characterized by more important landings. The fishing activities in the SAM were thus finally composed of 6 fishing fleets: south small fishing, south coastal fishing, south off-shore fishing, north small fishing, north coastal fishing and north off-shore fishing.

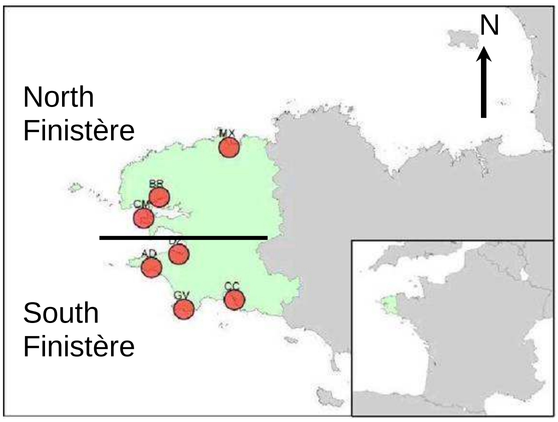


Fig. 2. Map showing the location of the 7 maritime districts of Finistère. MX = Morlaix; BR = Brest; CM = Camaret; DZ = Douarnenez; AD = Audierne; GV = Le Guilvinec; CC = Concarneau

2. Salerno

The fishing activities selected for the Salerno SAM are the following five fishing segments: bottom trawlers, purse-seiners, small-scale fishery, multipurpose fishery and tuna fleet. The above fleet classification is the one followed by the Irepa monitoring system of the Italian fishing fleet. This classification[5] is based on the statistics of the national Fishing License Register and on information about the prevailing fishing gears.

The first two fishing segments (bottom trawlers and purse-seiners) include vessels using, during the year, only one fishing gear (respectively trawler nets for bottom trawler and seines for purse-seiners). More heterogeneous is the composition of vessels belonging to the small scale fishery and to the multipurpose one. In these last two cases, indeed, vessels use a number of different fishing techniques. In particular, the fleet of the small scale fishery consists of vessels with the following characteristics; 1) overall length less than 12 meters; 2) use of passive selective gears, such as gillnets, hooks, traps and other techniques; no authorisations for pelagic pair trawls or bottom trawls; 3) technical and administration management carried out by a family member or at an artisanal level. Small scale vessels are very heterogeneous among them, as they use different fishing techniques depending on the seasons, on the resources abundance and on the climatic conditions. As far as the multipurpose segment, it includes vessels using, during the year, more than one fishing gear but, in this case, vessels are longer than 12 meters. Vessels belonging to this fishing fleet are very heterogeneous among them as, depending on the fishing technique mainly used and on the fishing area they present structural and operative features highly different.[6] Finally, the definition of the tuna fleet is clearly related to the target species, being red tuna and other tuna, such as albacore, etc…The tuna fleet is strongly related to the Salerno fishery, as this fleet has its home in the Salerno province. Its local name is "Associazione dei Produttori Tonnieri del Tirreno" and constitutes the most important reality for tuna production at local, regional and national level. Even if based in Salerno, the tuna fleet vessels operate in Mediterranean waters. In particular tuna catches come from Adriatic, Ionian, Sicilian and Ligurian seas. The fishing technique used by this fleet segment is the big purse-seine.

In the Salerno province, whose territory coincides with one of the administrative district of the Campania region[7], there are 15 enrolment offices, as shown in figure 3.

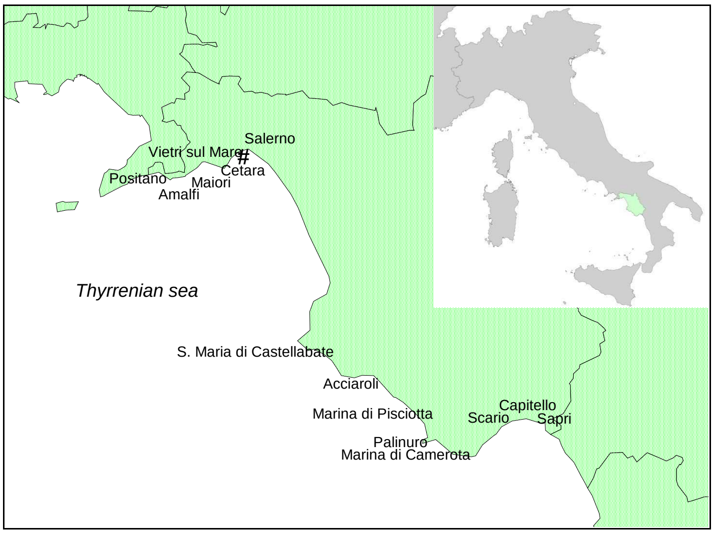


Fig. 3. Map showing the location of the 15 enrolment offices of the Salerno province. Source: Irepa.

[5] It must be outlined that since 2002, the Irepa classification of fishing vessels has been modified in order to comply with the EU regulations on data collection. Anyway, the adjustments are not very remarkable.
[6] In the more recent years Irepa is carrying out a work aimed to classify, in a way as precise as possible, the multipurpose vessels.
[7] The other ones are: Naples, Torre del Greco and Castellammare di Stabia.

In the selection of the fishing activities to be included in the Salerno SAM, no reference has been made to the distance of fishing. It depends on the fact that the greatest part of the Salerno fishing fleet is characterised by being a very coastal fishing fleet. Of the total vessels, about 93% exercise the fishing activity within the 12 nautical miles line (local coastal fishery). Among these last vessels, about 67% do not fish outside the 3 miles. They are mainly small scale vessels. The inshore coastal area (out of 40 miles) is populated by only a 5% of the Salerno fishing fleet and, mostly, by the demersal bottom trawlers. Only 2% of the fleet, made up of 13 vessels, fish in the Mediterranean waters. They are, as said before, the tuna fleet vessels, based in Salerno but catching tuna in Mediterranean waters. Making reference to the GFCM sub-geographical areas, it can be assessed that all the vessels based in the Salerno province operate within area while the tuna vessels mainly fish in the Adriatic (sub-geographical area 17 and 18), Ionian (19), in the waters south of Sicily (15 and 16) and in the Ligurian sea (9).

3. Cornwall

The large majority of fish production in Cornwall comes from small and medium fishing vessels that operate very close to the shore. In 2001, about 90% of the catches came from ICES subdivisions VIIe (49%), VIIf (24%) and VIIh (16%) which are located very close to the Cornwall shoreline (Fig. 4). For Cornwall, all the fleet segments that the national fisheries economics statistics (DEFRA) files have, were used. These corresponded to 6 fleet segments that are the EC gear segments: i) beam trawl ii) demersal trawls, seines and nephrops iii) lines and nets iv) shellfish fixed gear v) shellfish mobile gear vi) small scale coastal (<10m). In addition, a number of vessels for which the fleet segment is “unknown“ were regrouped in a segment that only represented 4% of the value landed in 2001. This is a mixed bag, according to DEFRA, mainly including either foreign vessels or the small “10m and under” vessels. In 2001, the beam trawlers represented more than one third of the total landings in value (37%), but this corresponded to 24% of the production in tonnage. On the other hand, lines and nets and small scale boats harvest species of high value because they represent 16% and 14% of the landings in tonnage respectively, but 20% and 19% in value respectively. These 2 fishing segments mostly operate in subdivision VIIe.

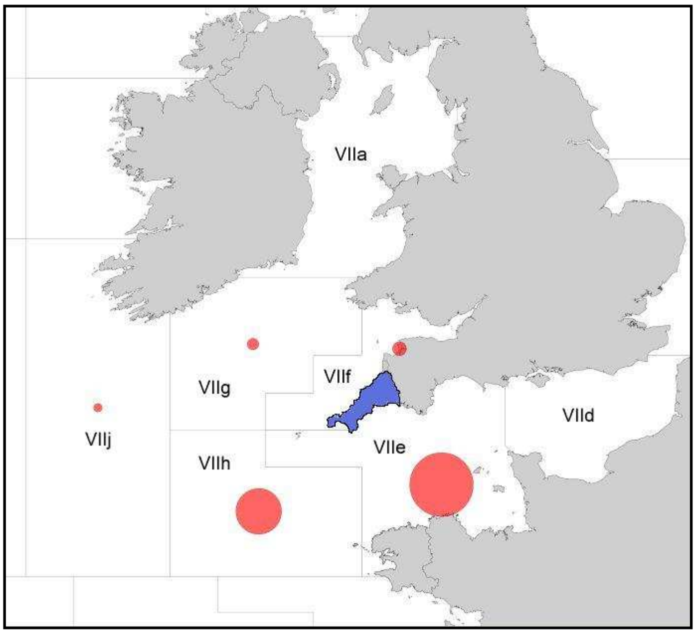


Fig. 4. Location of Cornwall province (blue) and ICES subdivisions where fishing fleets operate. Red circles indicate the relative importance of each subdivision in total landings in 2001 (tonnage).

4. Bornholm

For the Bornholm province, 5 fleet segments were considered according to the ministry of Food Agriculture and Fishery: i) trawlers less than 50 GT ii) trawlers larger than 50 GT iii) netters less than 12 m iv) netters larger than 12 m v) other vessels. This typology combines the type of gear (net or trawl) and the capacity of the vessels in terms of gross tonnage or vessel length, more appropriate for netters. No data were available at the level of the subdivisions of the International Baltic Sea Fishery Commission (IBSFC) to describe and analyse the geographic extent of the Bornholm fishing fleets within the Baltic Sea. They harvest cod on eastern (25-32) and western (22-24) parts of the Baltic and may operate relatively far from landing harbours for the trawlers larger than 50 GT (Fig. 5). The shrimp from Greenland included in the Bornholm fleet is only composed of 1 vessel, the "Ocean Tiger". It is driven through a multinational cooperation Ocean Prawns A/S (limited company) based in Nexø Bornholm and shrimp catches are never landed in the region.

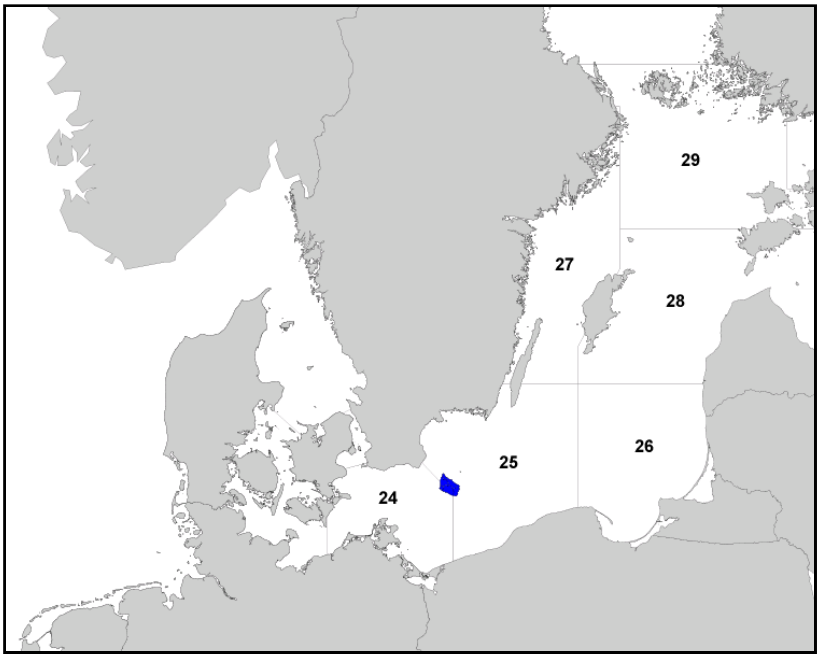


Fig. 5. Location of the island of Bornholm (blue) and IBSFC subdivisions.

5. Pontevedra

In the province of Pontevedra, 7 fishing segments were selected, including shellfish and fish farming: i) inshore fishing ii) coastal fishing iii) deep-sea fishing iv) high-sea fishing v) mussel farming vi) marine fish farming vii) shellfish gathering. The typology about fishing was thus mainly based on the distance to fishing that is closely related to the fish populations harvested. This allowed to easily make the correspondence between the fishing activity in the SAM and the stocks dynamics, when stock assessment reports were available. Fish and especially shellfish farming activities are mostly located within the Galician rias comprising 25% of the Iberian Peninsula coastline. Inshore and coastal fishing segments correspond to vessels that operate within the ICES subdivisions VIIIc and IXa that are located along the shorelines of Spain and Portugal (Fig. 6). Deep-sea fishing activity mainly concerns larger vessels that can reach the Bay of Biscay and the Irish Sea to target Norway lobster (*Nephrops norvegicus*), megrim (*Lepidorhombus spp.*), hake (*Merluccius merluccius*) and anglerfish (*Lophius spp.*). High-sea fishing concerns vessels longer than 24m which correspond to power superior to 150 GT. They operate very far from the Spanish coasts, in Greenland waters, West Africa and off South America to harvest hake (*Merluccius hubbsi*), squids (*Loligo spp.*) and Greenland halibut (*Reinhardtius hippoglossoides*). Fish can be processed onboard and few data are available on their catches and on the areas where they operate, because legislation in high-sea waters remains less restrictive than in exclusive economic zones (EEZ).

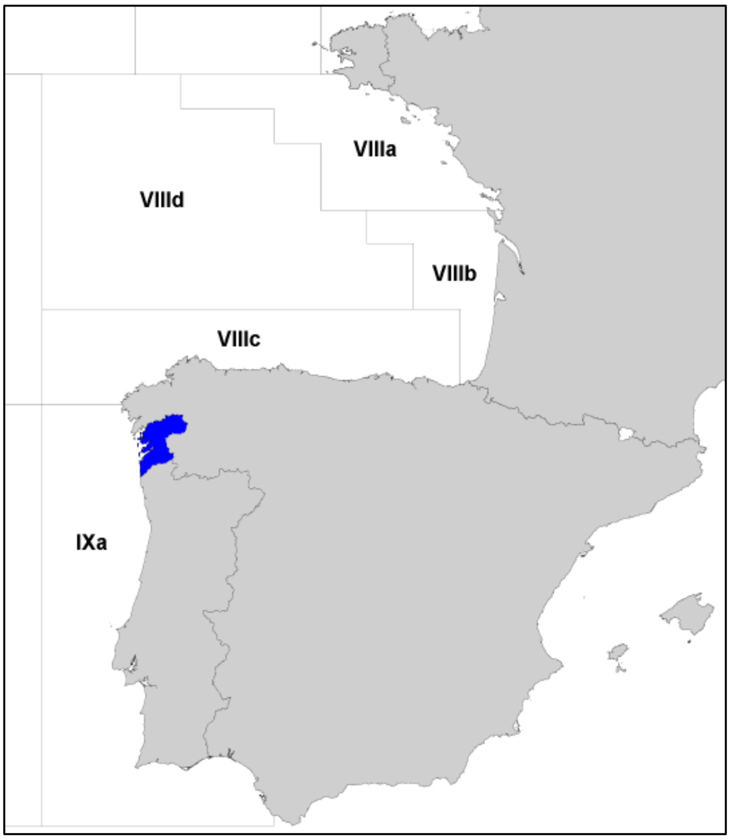


Fig. 6. Location of the Pontevedra province (blue) and ICES subdivisions.

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[i] See Dervis et al (1982) page 483 for an approach based on the Frisch parameter.